PATENT ABSTRACTS OF JAPAN

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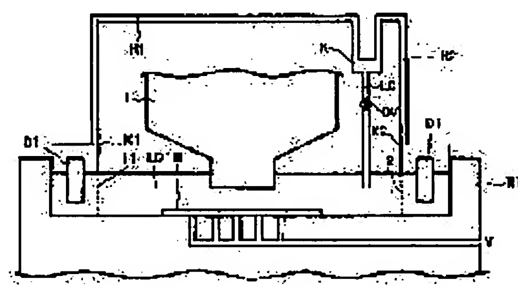
(54) ALIGNER, ITS MANUFACTURE, EXPOSING METHOD AND DEVICE MANUFACTURING METHOD

(57)Abstract:
PROBLEM TO BE SOLVED: To enable continuous correction of imaging performance without vibration, by installing a refractive index adjusting means for adjusting the refractive index of liquid.

SOLUTION: A refractive index adjusting means consists of the following; electrodes D1, ion exchange films 11, 12, bulkheads K1, K2, exhaust pipes H1, H2, a mixer K, an electromagnetic valve DV, an introducing pipe LD, a power source supply part and a second control part. The second control part sends a command to the power source supply part, and applies 8 specified voltage for a specified period across the two electrodes D1. From one electrode turning to an anode, oxygen gas is generated. From the other electrode turning to a cathode, mixed gas of hydrogen and chlorine is generated. Since the concentration of hydrogen chloride in liquid LQ is decreased, the refractive index of the liquid LQ is decreased. The second control part sends a command to the electromagnetic valve DV, in order to open the valve DV and add high concentration admixture aqueous solution to the liquid LQ. Thereby the refractive index of the liquid LQ is increased.



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CLAIMS

[Claim(s)]
[Claim 1] the aligner characterized by to have the illumination-light study system which illuminates the pattern prepared on the reticle, and the projection optics which forms the image of this pattern on a photosensitive substrate, and to have a refractive-index adjustment device for adjusting the refractive index of said liquid in the aligner exposed through the liquid which a part is boiled in the optical path between said projection optics and said photosensitive substrates at least, and is located.
[Claim 2] Said refractive-index adjustment device is an aligner according to claim 1 characterized by adjusting the refractive index of said liquid so that the image formation engine performance of said projection optics may be amended.
[Claim 3] It is the aligner according to claim 2 which is further equipped with an image formation performance-measurement means to measure the image formation engine performance of said projection optics, and is characterized by said refractive-index adjustment device adjusting the refractive index of said liquid so that said image formation engine performance may be amended.
[Claim 4] It is the aligner according to claim 1 which is further equipped with a fluctuation factor detection means to detect the condition of the factor of fluctuation of the image formation engine performance of said projection optics, and is characterized by said refractive-index adjustment device adjusting the refractive index of said liquid so that said image formation engine performance may be amended according to the condition of said factor.
[Claim 5] It is the aligner according to claim 4 which said illumination-light study system is constituted possible [modification of the lighting conditions over said reticle], and said fluctuation factor detection means detects the condition of said lighting conditions, and is characterized by said refractive-index adjustment device adjusting the refractive index of said liquid so that said image formation engine performance may be amended according to modification of said lighting conditions.
[Claim 6] It is the aligner according to claim 4 which said fluctuation factor detection means distinguishes the class of said reticle, and is characterized by said refractive-index adjustment device adjusting the refractive index of said liquid so that said image formation engine performance may be amended according to the class of said reticle.
[Claim 7] It is the aligner of six claim 1 characterized by having further a photosensitive substrate electrode holder holding said photosensitive substrate, and equipping this photosensitive substrate electrode holder with the side attachment wall for filling the optical path between said projection optics and said photosensitive substrates with said liquid, and supply / recovery unit for collecting from said photosensitive substrate electrode holder while supplying said liquid to said photosensitive substrate electrode holder thru/or given in any 1 term.
[Claim 8] Said refractive-index adjustment device is the aligner of seven claim 1 characterized by having the additive supply unit which supplies the additive for adjusting a refractive index to said liquid, and an additive recovery unit for collecting said additives from said liquid thru/or given in any 1 term.
[Claim 9] The exposure approach characterized by to include the process which adjusts the refractive index of said liquid in order to amend the image-formation engine performance of said projection optics under predetermined lighting conditions in the exposure approach of leading the light from said projection optics to said photosensitive substrate through a predetermined liquid, including the process which illuminates a reticle, and the process which imprints the pattern prepared on said reticle to a photosensitive substrate using projection optics.
[Claim 10] The process which illuminates a reticle under predetermined lighting conditions, and the process which imprints the device pattern prepared on said reticle to a photosensitive substrate using projection

optics are included. The device manufacture approach characterized by changing the refractive index of said liquid in the device manufacture approach of leading the light from said projection optics to said photosensitive substrate through a predetermined liquid when at least one side is changed among said reticle and said lighting conditions.
[Claim 11] It has the illumination-light study system which illuminates the pattern prepared on the reticle, and the projection optics which forms the image of this pattern on a photosensitive substrate. In the manufacture approach of the aligner which a part is boiled in the optical path between said projection optics and said photosensitive substrates at least, and is exposed through the located liquid The manufacture approach of the aligner characterized by including the process which measures the image formation engine performance of said projection optics, and the process which defines the initial value of the refractive index of said liquid based on the this measured image formation engine performance.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the device manufacture approach at the exposure approach list using an aligner and this aligner equipped with the projection optics which projects that of the device pattern prepared on the reticle on a photosensitive substrate. This invention relates to the immersion photolithography system which filled up the optical path between projection optics and a photosensitive substrate with the liquid in more detail. In case this invention manufactures a semiconductor device, image sensors (CCD etc.), a liquid crystal display component, or the thin film magnetic head, it is suitable.
[0002]
[Description of the Prior Art] Although the space between the last side of optical system and the image surface was called working distance, working distance was filled with air according to the projection optics of the conventional aligner. By the way, the detailed-ization is always desired, and the pattern exposed to a silicon wafer in the process in which IC and LSI are manufactured needs to shorten wavelength of the light used for exposure for that purpose, or needs to enlarge numerical aperture by the side of an image. The glass ingredient only with the permeability which can secure the quantity of light satisfied with exposure decreases obtaining the satisfying image formation engine performance as the wavelength of light becomes short.
[0003] Then, the aligner in which enlarging numerical aperture by the side of an image by using the last medium to the image surface as a liquid with a larger refractive index than air is proposed, and it has the projection optics using a liquid such is called the immersion photolithography system. Now, in the aligner, in order to amend the image formation engine performance of projection optics, the technique of projection optics of preparing the optical path by the side of a body or the image formation engine-performance amendment member for adjusting the image formation engine performance into the optical path by the side of an image most exchangeable is known most.
[0004]
[Problem(s) to be Solved by the Invention] However, since it is the configuration of filling a liquid with an immersion photolithography system to the optical path between projection optics and a photosensitive substrate (working distance), it is difficult to arrange the member for amending the image formation engine performance. Moreover, since considering the configuration of the number of finite, and realistic equipment such an image formation engine-performance amendment member can prepare only extent partly, it has the trouble which cannot amend the discrete image formation engine performance.
[0005] Moreover, although it is necessary to store the image formation engine performance of projection optics in predetermined tolerance, if amendment of the image formation engine performance cannot be performed discretely as mentioned above, storing in this predetermined tolerance becomes difficult. If detailed-izing of an exposure pattern and increase of exposure area are searched for especially, the tolerance of this image formation engine performance becomes narrow, and also when performing the scan exposure approach exposed making a reticle and a photosensitive substrate scan, the tolerance of the range of fluctuation of image formation performance characteristics is narrow, and it cannot respond in discrete amendment.
[0006] Moreover, since vibration of the projection optics itself occurs at the time of exchange of the above image formation engine-performance amendment members, there is also a possibility that a bad influence may arise to the image formation engine performance. Then, this invention sets it as the 1st purpose to enable amendment of the continuous image formation engine performance, without being accompanied by vibration. Moreover, this invention sets coexistence with amending increase and the image formation engine

performance of the numerical aperture of projection optics as the 2nd purpose.
[0007]
[Means for Solving the Problem] in order to attain the 1st above-mentioned purpose, the aligner by this invention has the illumination-light study system which illuminates the pattern prepared on the reticle, and the projection optics which form the image of this pattern on a photosensitive substrate, and it is the aligner exposed through the liquid which a part is boiled in the optical path between projection optics and a photosensitive substrate at least, and is located, and it has a refractive-index adjustment device for adjusting the refractive index of a liquid.
[0008] Here, according to the desirable mode hung up over above-mentioned claim 2, a refractive-index adjustment device adjusts the refractive index of a liquid so that the image formation engine performance of said projection optics may be amended. According to the desirable mode hung up over claim 3 based on this configuration, it has further an image formation performance-measurement means to measure the image formation engine performance of projection optics, and a refractive-index adjustment device adjusts the refractive index of a liquid so that said image formation engine performance may be amended.
[0009] Moreover, according to the desirable mode hung up over claim 4, it has further a fluctuation factor detection means to detect the condition of the factor of fluctuation of the image formation engine performance of projection optics, and according to the condition of a factor, a refractive-index adjustment device adjusts the refractive index of a liquid so that the image formation engine performance may be amended. According to the desirable mode hung up over claim 5 based on this configuration, an illumination-light study system is constituted possible [modification of the lighting conditions over said reticle], a fluctuation factor detection means detects the condition of lighting conditions, and according to modification of lighting conditions, a refractive-index adjustment device adjusts the refractive index of a liquid so that the image formation engine performance may be amended.
[0010] And according to the desirable mode hung up over claim 6, a fluctuation factor detection means distinguishes the class of reticle, and according to the class of reticle, a refractive-index adjustment device adjusts the refractive index of a liquid so that the image formation engine performance may be amended. Moreover, in order to attain the 2nd above-mentioned purpose, it is desirable to fill all the optical paths between projection optics and a photosensitive substrate with a liquid. As for the aligner by this invention, at this time, it is desirable to have further the photosensitive substrate electrode holder which is equipped with the side attachment wall for filling the optical path between projection optics and a photosensitive substrate with said liquid and supply / recovery unit for collecting from said photosensitive substrate electrode holder while supplying a liquid to said photosensitive substrate electrode holder, and holds a photosensitive substrate.
[0011] Moreover, as for a refractive-index adjustment device, it is desirable to have the additive supply unit which supplies the additive for adjusting a refractive index to a liquid, and an additive recovery unit for collecting said additives from a liquid.
[0012]
[Embodiment of the Invention] In this invention like an above-mentioned configuration, since the refractive index of the liquid located in the optical path between projection optics and a photosensitive substrate can be adjusted, change of this refractive index can amend the image formation engine performance of projection optics. As the technique of refractive-index adjustment here, supposing a liquid is a mixed liquor object of many matter, the refractive index n of this mixed liquor object will follow the formula of Lorentz Lawrence (Lorentz-Lorenz), and it is [0013].
[Equation 1]

$$\left(\frac{n^2-1}{n^2+2}\right) = \sum_{i=1,2,\ldots} m_{(i)} \times \left(\frac{n_{(i)}{}^2-1}{n_{(i)}{}^2+2}\right) \times \frac{\rho}{\rho_{(i)}}$$

[0014] It becomes. However, [0015]
[Equation 2]
$n_{(i)}$: i番目の物質の屈折率、
$m_{(i)}$: i番目の物質の重量分率、
$\rho_{(i)}$: i番目の物質の密度、

[0016] It comes out. For example, what is necessary is just to make the concentration of the matter added to

a water solution fluctuate, since the refractive index of this water solution will change according to the concentration of the water solution itself, if a liquid is used as a water solution. If the refractive index of a liquid is changed so that this may become the value of the refractive index which can compensate the image formation engine performance of projection optics, the image formation engine performance of projection optics will become good.
[0017] Here, adjustment of a refractive index may measure image formation engine performance, such as aberration of projection optics, may adjust a refractive index according to the result, may detect fluctuation of the factor corresponding to fluctuation of the image formation engine performance of projection optics, and may adjust a refractive index according to the result. In the technique of measuring the image formation engine performance of the former projection optics, the aberration of projection optics etc. may be measured at the time of manufacture of an aligner, and the value of the refractive index which compensates this aberration may be set as the initial value of the refractive index of a liquid. Thus, if a refractive index is adjusted as a part of adjustment at the time of manufacture, there is an advantage from which manufacture and adjustment become easy. Moreover, the aberration measurement device etc. is prepared in the aligner itself, and the refractive index of a liquid may be changed according to the aberration measurement result by this aberration measurement device.
[0018] On the other hand, as fluctuation of the factor corresponding to fluctuation of the latter image formation engine performance, the amount of exposure energy which passes the class of reticle, the condition of lighting conditions, and projection optics is mentioned. here, if the optimal thing is decided by the class of pattern established on a reticle and lighting conditions at the time of illuminating a reticle, such as etc., a sigma value and deformation lighting ****** -- change this lighting condition according to it, the image formation engine performance which makes aberration of projection optics the start will change. What is necessary is to make memory etc. memorize beforehand the value of the refractive index for compensating the image formation engine performance which changes with fluctuation of this factor for every factors, such as a class of reticle, and lighting conditions, to detect fluctuation of this factor and just to adjust the refractive index of a liquid there based on the memorized relation. Moreover, what is necessary is to make memory etc. memorize beforehand the value of the refractive index for compensating the image-formation engine performance which changes with the size of the amount of exposure energy, and this amount of exposure energy also in this case, to detect fluctuation of this factor and just to adjust the refractive index of a liquid based on the memorized relation, although there is the so-called exposure fluctuation from which the image-formation engine performance of projection optics changes with the size of the amount of exposure energy which passes projection optics. In addition, in this technique, you may compute in a predetermined formula instead of making memory memorize.
[0019] Thus, it is effective for especially amendment of spherical aberration and a curvature of field among the image formation engine performance of projection optics by adjusting the refractive index of a liquid. Hereafter, the gestalt of operation concerning this invention is explained with reference to a drawing.
[Gestalt of the 1st operation] drawing 1 is drawing showing roughly the aligner by the gestalt of the 1st operation concerning this invention. In addition, XYZ system of coordinates are adopted in drawing 1 .
[0020] In drawing 1 , the light source S supplies exposure light with a wavelength of 248nm, and the exposure light from this light source S illuminates Reticle R under almost uniform illumination distribution through the illumination-light study system IL and a reflecting mirror M. Here, although the KrF excimer laser is used as the light source S in this example instead, the high-pressure mercury lamp which supplies the ArF excimer laser which supplies 193nm exposure light, g line, i line, etc. may be used. Moreover, in drawing 1 , although not illustrated, the illumination-light study system IL has the optical integrator for forming the surface light source, the capacitor optical system for condensing the light from this surface light source, and carrying out homogeneity lighting of the irradiated plane in superposition, and an adjustable aperture diaphragm for being arranged in the location of the surface light source formed by the optical integrator, and making the configuration of the surface light source adjustable. Here, it is what has two or more surface light sources which carried out eccentricity from the optical axis as a configuration of the surface light source, the thing of a zona-orbicularis configuration, and a circle configuration, and the magnitude has a so-called thing etc. As such an illumination-light study system IL, what is indicated by the U.S. Pat. No. 5,329,094 official report and the U.S. Pat. No. 5,576,801 official report, for example can be used.
[0021] And the exposure light which passed and diffracted Reticle R reaches on Wafer W through projection optics T, and the image of Reticle R is formed on a wafer. Here, Reticle R is held by the reticle loader RL, and the reticle loader RL is constituted so that it can move at the rate of arbitration on the X-axis

and a Y-axis with a driving gear T1 in the loader table LT top at the time of arbitration. Here, the passing speed on the loader table LT of a reticle loader RL is detected by the rate sensor SS, and the output from this rate sensor SS is transmitted to the 1st control section CPU 1.
[0022] Moreover, Wafer W is held on the wafer table WT. The side attachment wall for collecting Liquids LQ is prepared in this wafer table WT. In this example, it has the composition that all the optical paths from Wafer W to projection optics T are filled with Liquid LQ, with this side attachment wall. This wafer table WT is constituted so that it can move to X shaft orientations and Y shaft orientations at the rate of arbitration on the electrode-holder table HT with a driving gear T2.
[0023] Here, the 1st above-mentioned control section CPU 1 computes the passing speed on the electrode-holder table of the wafer table WT from the passing speed on the loader table LT of a reticle loader RL, and the exposure scale factor beta of projection optics T, and transmits it to a driving gear T2. A driving gear moves the wafer table WT based on the passing speed transmitted from the 1st control section CPU 1.
[0024] Drawing 2 is drawing which expressed the configuration of this wafer table WT to the detail. this drawing 2 -- setting -- projection optics T -- most, between the optical member by the side of Wafer W, and the metal flask of projection optics T, it has stuck so that Liquid LQ may not permeate, or packing is carried out. Moreover, two or more openings are prepared in the pars basilaris ossis occipitalis of the wafer table WT, and Wafer W is adsorbed by the wafer table WT by decompressing from the piping V connected to these openings. And electrodes D1 and D2 are formed in the wafer table WT, and ion exchange membrane I1 and I2 is formed in each perimeter of these electrodes D1 and D2. The perimeter of electrodes D1 and D2 and the field where exposure light passes Liquid LQ are divided by such ion exchange membrane I1 and I2. Here, the ambient atmosphere around an electrode D1 serves as a closed space by ion exchange membrane I1 and the septum K1, and the exhaust pipe H1 is connected to this closed space. Moreover, the ambient atmosphere around an electrode D2 serves as a closed space by ion exchange membrane I2 and the septum K2, and the exhaust pipe H2 is connected to this closed space. Both these exhaust pipes H1 and H2 are connected to Mixer K. The end of the introductory tubing LD equipped with the solenoid valve DV is connected to this mixer K, and the other end of this introductory tubing LD is located near the wafer table WT.
[0025] The seal-of-approval electrical potential difference which the seal-of-approval electrical potential difference to electrodes D1 and D2 is supplied from the current supply section without illustration, and the current supply section supplies is controlled by the 2nd control section CPU 2. Moreover, ** and the 2nd control section CPU 2 control also about closing motion of a solenoid valve DV. These electrodes D1 and D2, ion exchange membrane I1 and I2, septa K1 and K2, exhaust pipes H1 and H2, Mixer K, a solenoid valve DV, the introductory tubing LD, the current supply section without illustration, and the 2nd control section CPU 2 constitute the refractive-index adjustment device from this example.
[0026] Hereafter, actuation of a refractive-index adjustment device is explained. In the following explanation, Liquid LQ supposes that a hydrogen chloride is added to pure water as an additive. First, when lowering the refractive index of Liquid LQ, as for the 2nd control section CPU 2, only predetermined time amount carries out the ** mark of the predetermined electrical potential difference for a command between delivery, an electrode D1, and an electrode D2 to the current supply section. At this time, an oxygen gas occurs from the electrode used as an anode plate, and the mixture of gas of hydrogen and chlorine occurs from the electrode used as cathode. Since the hydrogen chloride concentration in Liquid LQ falls at this time, as shown also in the above-mentioned (1) formula, the refractive index of Liquid LQ falls. Since the gas generated near each electrodes D1 and D2 does not pass ion exchange membrane I1 and I2, it can be collected through exhaust pipes H1 and H2 here. This collected gas is sent to Mixer K. In Mixer K, the collected gas (an oxygen gas, a hydrogen gas, hydrogen chloride gas) is mixed, and the additive water solution of high concentration [Liquid / LQ] is generated from this.
[0027] Moreover, when gathering the refractive index of Liquid LQ, the 2nd control section CPU 2 sends a command to a solenoid valve DV so that a solenoid valve DV may be opened and a high-concentration additive water solution may be added to Liquid LQ. Thereby, the refractive index of Liquid LQ rises. By this configuration, the refractive index of Liquid LQ is made to adjustable. Now, it corresponds to the memory M1 connected to the 2nd control section CPU 2 for every various lighting conditions, and the value of a refractive index is memorized in the form of a table. Here, the value of a refractive index is a value of the refractive index of the liquid LQ required in order to amend the aberration produced in projection optics T under a certain lighting condition. Moreover, the value of the additive concentration in the liquid LQ at a certain time is kept by this memory M1 in the form always updated.
[0028] Moreover, the above-mentioned illumination-light study system IL is connected with the 2nd control

section CPU 2 in order to transmit the information about the configuration of the surface light source which this illumination-light study system IL forms to the 2nd control section CPU 2. Here, in the example of a lighting condition-book, change of configuration - of the surface light source transmits this information to the 2nd control section CPU 2. At this time, the 2nd control section CPU 2 searches the value of the refractive index corresponding to the transmitted lighting conditions from memory M1, and calculates the concentration of the additive for realizing that refractive index from the above-mentioned (1) formula. Next, the 2nd control section CPU 2 controls electrodes D1 and D2 or a solenoid valve DV to consider as the additive concentration which had current additive concentration calculated according to the current additive concentration currently kept by memory M1 and the calculated additive concentration.
[0029] Thereby, the aberration of the projection optics T when the value of the refractive index of Liquid LQ includes Liquid LQ is amended.
It differs greatly in that the gestalt of [gestalt of the 2nd operation] the 2nd operation used the additive in the gestalt of the 1st operation as ethyl alcohol. This ethyl alcohol does not dissolve the resist layer of the wafer W with which the resist as a photosensitive substrate was applied, but has an advantage with little effect on the optical coat in projection optics T most given to the optical member (optical member which touches Liquid LQ) and this optical member by the side of Wafer W.
[0030] Moreover, in the gestalt of the 2nd operation, the configuration of a refractive-index adjustment device differs from the thing of the gestalt of the 1st operation. Hereafter, with reference to drawing 3 , it explains per configuration of a refractive-index adjustment device. In addition, in drawing 3 , the same sign is given to the member which has the same function as what was shown in drawing 2 . In drawing 3 which shows the wafer table WT by the gestalt of the 2nd operation, the thing of the gestalt of the 1st operation is the point of having the exhaust pipe L which discharges Liquid LQ so that the pure-water supply pipe WS and Liquid LQ for supplying the additive supply pipe LS and pure water for a different point supplying an additive to Liquid LQ to Liquid LQ may not overflow from the wafer table WT.
[0031] Here, the solenoid valve DVL for adjusting the solenoid valves DVLS and DVWS for adjusting the amount of supply of an additive and pure water and the discharge of Liquid LQ to the additive supply pipe LS, the pure-water supply pipe WS, and an exhaust pipe L is formed, respectively, and closing motion of these solenoid valves DVLS, DVWS, and DVL is controlled by the 2nd control section CPU 2. The actuation at the time of the refractive-index adjustment in the gestalt of the 2nd operation is explained.
[0032] First, when gathering the refractive index of Liquid LQ, a solenoid valve DVLS is controlled and, as for the 2nd control section CPU 2, only a predetermined amount adds an additive to Liquid LQ. At this time, only a predetermined amount discharges Liquid LQ from an exhaust pipe L. As for the amount of this liquid LQ to discharge, it is desirable that it is the same as the amount of the added additive. Thereby, the additive concentration in Liquid LQ increases and the refractive index rises.
[0033] Moreover, when lowering the refractive index of Liquid LQ, a solenoid valve DVWS is controlled and, as for the 2nd control section CPU 2, only a predetermined amount adds pure water to Liquid LQ. At this time, only a predetermined amount discharges Liquid LQ from an exhaust pipe L. As for the amount of this liquid LQ to discharge, it is desirable that it is the same as the amount of the added pure water. Thereby, the additive concentration in Liquid LQ becomes low, and the refractive index falls.
[0034] Here, the amount of the additive added and pure water and the amount of the liquid LQ to discharge are controlled by the 2nd control section CPU 2. In addition, the point that the value of a refractive index is memorized in memory M1 corresponding to the class of lighting conditions, and the point that the value of the additive concentration of the liquid LQ at a certain time is kept are the same as the gestalt of the 1st operation of a ****, and the point of them which calculates the additive concentration for realize the refractive index which can amend the aberration of projection optics T based on such information is the same as the gestalt of the 1st operation.
[0035] Thus, the 2nd control section CPU 2 in the gestalt of the 2nd operation controls closing motion of solenoid valves DVLS, DVWS, and DVL to consider as the additive concentration which had current additive concentration calculated according to the current additive concentration currently kept by memory M1 and the calculated additive concentration. Thereby, the aberration of the projection optics T when the value of the refractive index of Liquid LQ includes Liquid LQ is amended.
The gestalt of the 3rd operation is explained with reference to [the gestalt of the 3rd operation], next drawing 4 . The aligner by the gestalt of the 3rd operation differs from the gestalt of the above-mentioned 1st and the 2nd operation at a point equipped with the aberration measuring device. In addition, in drawing 4 , the same sign is given to the member which has the same function as the example of above-mentioned drawing 1 - drawing 3 , and the same XYZ system of coordinates as drawing 1 are adopted.

[0036] In drawing 4 , the light source S supplies exposure light with a wavelength of 248nm, and after the exposure light from this light source S is prepared according to the beam plastic surgery optical system 11 in the cross section of a predetermined configuration, it carries out incidence of it to the 1st fly eye lens 12. The secondary light source which consists of two or more light source images is formed in the injection side of the 1st fly eye lens 12. Incidence of the exposure light from this secondary light source is carried out to the 2nd fly eye lens 15 through the relay lens systems 13F and 13R. This relay lens system consists of pre-group 13F and rear group 13R, and the oscillating mirror 14 for preventing the speckle on an irradiated plane is arranged among such pre-group 13F and rear group 13R.
[0037] Now, two or more formation of the image of the secondary light source by the 1st fly eye lens is carried out, and this serves as the 3rd light source at the injection side side of the 2nd fly eye lens 15. The adjustable aperture diaphragm 16 which can set up two or more aperture diaphragms which have a predetermined configuration or predetermined magnitude in the location in which this 3rd light source is formed is arranged. This adjustable aperture diaphragm 16 forms six aperture diaphragms 16a-16e by which patterning was carried out on the transparence substrate which consisted of quartzes etc. in the shape of a turret, as shown in drawing 5 . Here, two aperture diaphragms 16a and 16b with circular opening are drawing for changing a sigma value (numerical aperture of the illumination-light study system to the numerical aperture of projection optics), and two aperture diaphragms 16c and 16d with a zona-orbicularis configuration are diaphragms from which a zona-orbicularis ratio differs mutually. And the two remaining aperture diaphragms 16e and 16f are diaphragms which have four openings which carried out eccentricity. By the adjustable aperture-diaphragm drive unit 17, this adjustable aperture diaphragm 16 is driven so that any or 1 of two or more aperture diaphragms 16a-16f may be located in an optical path.
[0038] Returning to drawing 4 , it is condensed by the condensing lens system 18 and the exposure light from the adjustable aperture diaphragm 16 illuminates a reticle blind 19 top in superposition. The reticle blind 19 is arranged about the relay optical system 20F and 20R conjugate [of Reticle R / the pattern formation side and conjugate], and the configuration of the lighting field on Reticle R is determined by the opening configuration of a reticle blind 19. The exposure light from a reticle blind 19 forms the lighting field of uniform illumination distribution in the position on Reticle R substantially through rear group 20R of pre-group 20F of relay optical system, a reflecting mirror M, and relay optical system.
[0039] In addition, the illumination-light study system IL in the gestalt of the above-mentioned 1st and the 2nd operation can also apply the beam plastic surgery optical system 11 shown in the gestalt of this operation - the relay optical system 20F and 20R. Now, Reticle R is laid on the reticle loader RL, and this reticle loader RL is movable on the electrode-holder table LT to the XY direction in drawing, and the hand of cut (the direction of theta) centering on the Z-axis. The migration mirror RIM is formed in this reticle loader RL, and the reticle interferometer RI detects the location of the XY direction of a reticle loader RL, and the direction of theta to it. Moreover, a reticle loader RL is driven in the XY direction and the direction of theta by the reticle loader drive unit RLD. Here, the output from the reticle interferometer RI is transmitted to the 1st control section CPU 1, and the 1st control section CPU 1 has composition which controls the reticle loader drive unit RLD.
[0040] Moreover, the bar code reader BR for reading the bar code prepared in Reticle R in the middle of the conveyance way from a reticle stocker without illustration is formed. The information about the class of reticle R which this bar code reader BR read is transmitted to the 2nd control section CPU 2. Here, the value of the refractive index of the optimal liquid LQ is remembered to be the information about the optimal lighting conditions for every class of reticle R for every class of reticle R by the memory M1 connected to the 2nd control section CPU 2.
[0041] the projection optics T which has predetermined contraction scale-factor |beta| prepares in Reticle R bottom -- having -- **** -- this projection optics T -- between the optical member by the side of a wafer side, and Wafer W, Liquid LQ intervenes most. Projection optics T forms the contraction image of Reticle R on a wafer side through this liquid LQ. Adsorption immobilization of the wafer W is carried out at the wafer table WT, and this wafer table WT is attached in the XY direction to the surface plate on the movable wafer stage WTS through the Z actuators ZD1, ZD2, and ZD3 for making migration to Z shaft orientations of wafer table WT itself, and a tilt (inclination to the Z-axis) perform. This wafer stage WTS is driven by the wafer stage drive unit WD. Moreover, mirror plane processing is performed and this part of the side attachment wall of a wafer table serves as a migration mirror of the wafer interferometer WI. Here, the drive of the wafer stage drive unit WD is controlled by the 1st above-mentioned control section CPU 1, and the output from the wafer interferometer WI has composition transmitted to the 1st control section CPU 1.
[0042] Moreover, the focal sensor AF for measuring the distance of the Z direction between projection

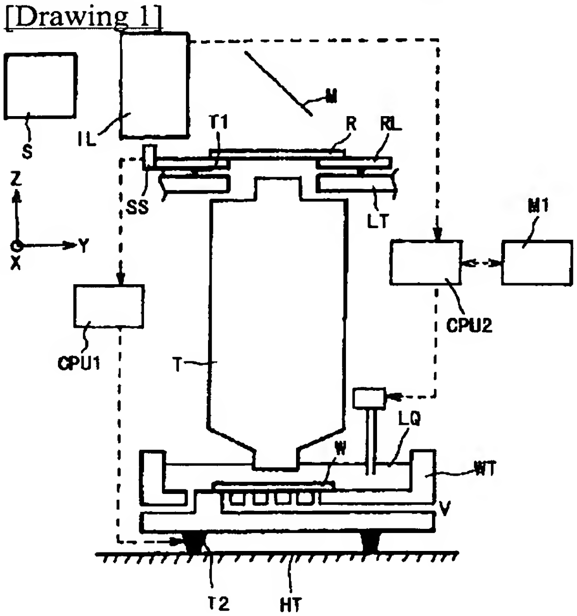
optics T and Wafer W is formed in projection optics T. This focal sensor AF receives the light which irradiated light on the wafer side through the optical element near the wafer W side in projection optics T, and was reflected with the wafer through the above-mentioned optical element, and measures the distance of the Z direction between projection optics T and Wafer W with that light-receiving location. The configuration of such a focal sensor AF is indicated by JP,6-66543,A.
[0043] Now, also in the gestalt of the 3rd operation, it has the pure-water supply pipe WS for supplying the pure water stored in the additive supply pipe LS and the pure-water storage section WST for supplying the high-concentration additive water solution stored in the additive storage section latest starting time to Liquid LQ to Liquid LQ, and the solenoid valves DVLS and DVWS for adjusting the amount of supply of an additive water solution and pure water are formed in the additive supply pipe LS and the pure-water supply pipe WS. Moreover, the exhaust pipe L for discharging Liquid LQ is formed in the wafer table WT so that Liquid LQ may not overflow from a wafer table, and the solenoid valve for adjusting the discharge of Liquid LQ is formed in this exhaust pipe L. Closing motion of these solenoid valves DVLS, DVWS, and DVL is controlled by the 2nd control section CPU 2 like the gestalt of the 2nd operation of a ****.
[0044] Moreover, on the wafer table WT, the additive concentration detecting element DS for detecting the additive concentration of the aberration test section AS for measuring the aberration of projection optics and Liquid LQ is formed. Here, as an aberration test section AS, what is indicated by JP,6-84757,A, for example can be used. Here, the output from the aberration test section AS and the additive concentration detecting element DS is transmitted to the 2nd control section CPU 2. Moreover, the output from the additive concentration detecting element DS minds the 2nd control section CPU 2, and is kept as a value of the additive concentration of the liquid LQ at a certain time to memory M1.
[0045] Next, actuation of the gestalt of the 3rd operation is explained. First, while Reticle R being taken out from a reticle stocker without illustration, and being laid on a reticle loader RL, a bar code reader BR reads the bar code prepared in Reticle R, and transmits the information to the 2nd control section CPU 2. The 2nd control section CPU 2 reads the information about the lighting conditions corresponding to the class of reticle R memorized by memory M1, controls the adjustable aperture-diaphragm drive unit 17 according to the information, and locates one of aperture diaphragms 16a-16f predetermined in an optical path. Moreover, the 2nd control section CPU 2 calculates the concentration of the additive for realizing the refractive index from the above-mentioned (1) formula based on the value of the refractive index of the liquid LQ memorized by memory M1. Then, closing motion of solenoid valves DVLS, DVWS, and DVL is controlled to consider as the additive concentration which had current additive concentration calculated according to the current additive concentration which is detected by the additive concentration detecting element DS and kept by memory M1, and the calculated additive concentration.
[0046] Thereby, the aberration of the projection optics T when the value of the refractive index of Liquid LQ includes Liquid LQ is amended. Then, the focal sensor AF detects the location and tilt of a Z direction of Wafer W, and the Z actuators ZD1, ZD2, and ZD3 are driven so that Wafer W may become a necessary location. In this condition, the exposure light from the light source S is led to Reticle R through an illumination-light study system, and the 1st control section CPU 1 detecting the location of Reticle R and Wafer W with the reticle interferometer RI and the wafer interferometer WI, it makes the reticle loader drive unit RLD and the wafer stage drive unit WD drive, and moves Reticle R and Wafer W under the velocity ratio of projection scale-factor |beta| of projection optics T. Thereby, the pattern on Reticle R is imprinted on Wafer W under a good image formation condition.
[0047] Now, the image formation engine performance (aberration etc.) of projection optics T always may not be fixed, and it may change with a temperature change, atmospheric pressure change, the temperature rises by projection optics T absorbing exposure light, etc. So, with the gestalt of the 3rd operation, the aberration (image formation engine performance) of the actual projection optics T is measured by the aberration test section AS, and it is considering as the configuration which adjusts the value of the refractive index of Liquid LQ based on this measurement result.
[0048] With the gestalt of the 3rd operation, it is the form where the aberration value of projection optics was made to correspond in memory M1, and, specifically, the value of the refractive index of the liquid LQ which can amend the aberration is memorized. And the aberration of the projection optics T detected by the aberration test section AS is transmitted to the 2nd control section CPU 2. The 2nd control section CPU 2 reads the value of the refractive index of the liquid LQ memorized in memory M1, it asks for additive concentration from the above-mentioned (1) formula so that it may become the value of this refractive index, and it controls closing motion of solenoid valves DVLS, DVWS, and DVL so that Liquid LQ serves as that additive concentration.

[0049] Even if there is an environmental variation (a temperature change, atmospheric pressure fluctuation, fluctuation by exposure light absorption) of projection optics T, that image formation engine performance is maintainable good with this configuration. In addition, what is necessary is not to always perform measurement by this aberration test section AS, and just to carry out for every predetermined period.
[the gestalt of the 4th operation] -- with reference to drawing 6 , the gestalt of the 4th operation is explained below. The gestalt of the 4th operation is considered as the configuration which fills a part of this optical path with a liquid instead of the configuration which fills all the optical paths between projection optics and a wafer with a liquid.
[0050] In drawing 6 (a) and (b), the same sign is lain down on the member which has the 1st shown in drawing 1 -3, and the same function as the gestalt of the 2nd operation. The configuration which fills Liquid LQ with the gestalt of the 4th operation in the containers C [C1 and] 2 which consisted of ingredients (for example, quartz etc.) which make exposure light penetrate instead of [which is shown in drawing 6 (a) and (b)] collecting Liquids LQ with the side attachment wall of wafer holder-WT differs from the gestalt of the above-mentioned 1st and the 2nd operation. By this configuration, although there is no effectiveness of numerical-aperture increase or effectual depth of focus expansion among the effectiveness which the gestalt of the above-mentioned 1st and the 2nd operation had, it has the effectiveness whose aberration (image formation engine performance) adjustment of projection optics T is attained continuously.
[0051] In addition, in the gestalt of this 4th operation, the containers C1 and C2 currently put into Liquid LQ may be formed in projection optics T and one. With the above gestalt of the 1st - the 4th operation, although pure water was used as a liquid LQ, it is not restricted to pure water.
[0052]
[Effect of the Invention] As shown above, according to this invention, the image formation engine performance of projection optics can be adjusted continuously without vibration. Moreover, it becomes possible to reconcile increase (or expansion of the effectual depth of focus) of numerical aperture, and adjustment of the image formation engine performance.

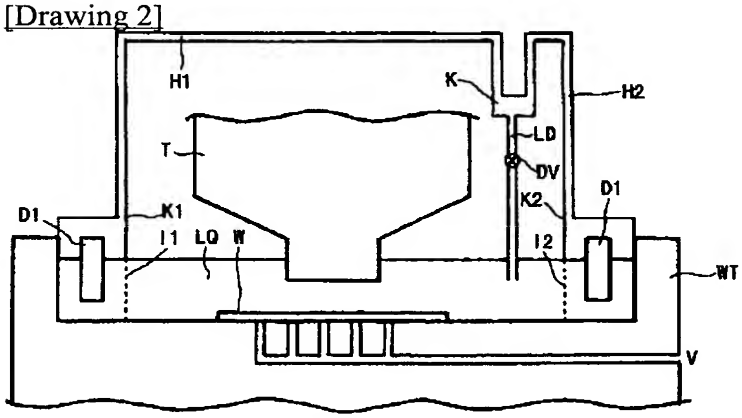
[Translation done.]

DRAWINGS

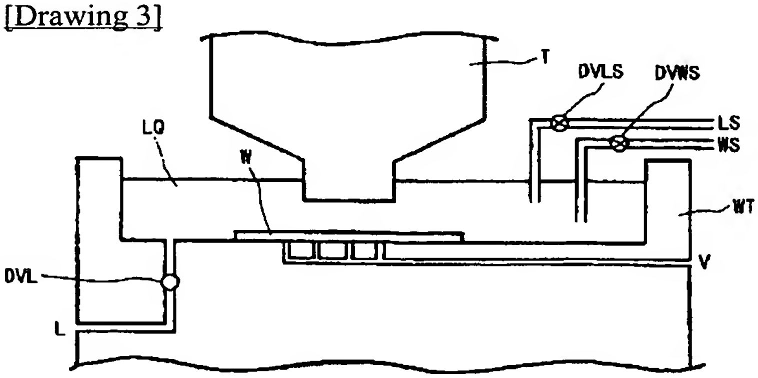
[Drawing 1]



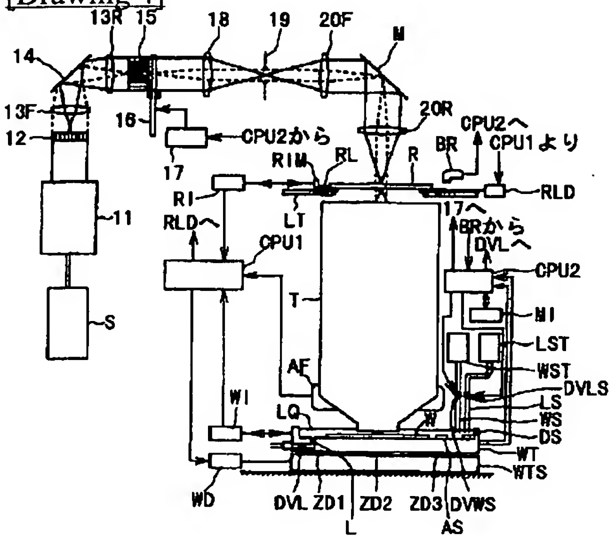
[Drawing 2]



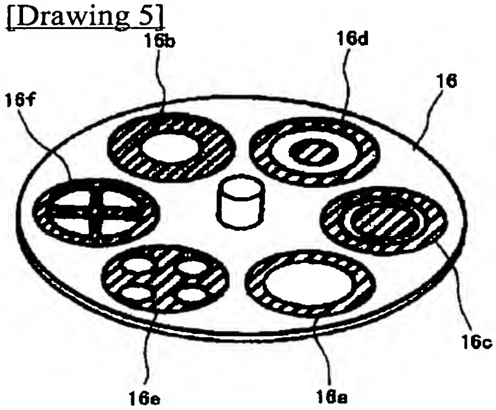
[Drawing 3]



[Drawing 4]

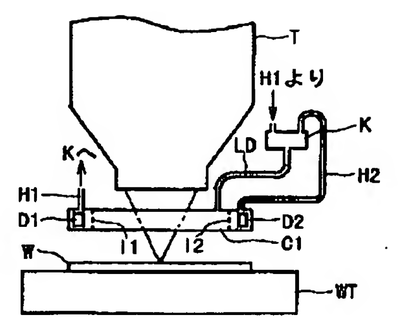


[Drawing 5]

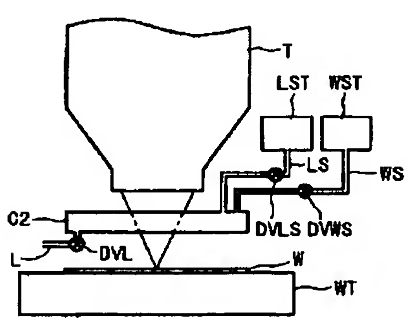


[Drawing 6]

(a)



(b)



[Translation done.]

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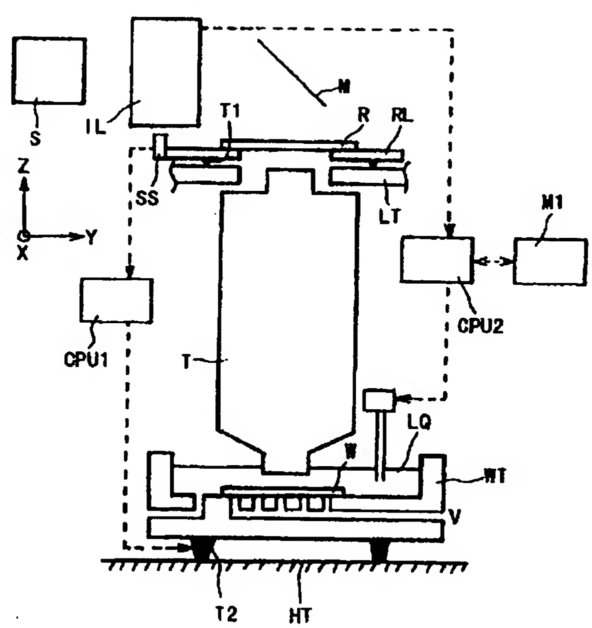
(54)【発明の名称】　露光装置及びその製造方法並びに露光方法及びデバイス製造方法

(57)【要約】
【課題】、連続的な結像性能の補正を振動を伴うことなく可能とすること、或いは投影光学系の開口数の増大及び結像性能の補正を両立すること
【解決手段】レチクルR上に設けられたパターンを照明する照明光学系ILと、このパターンの像を感光性基板上に形成する投影光学系Tとを有し、投影光学系と感光性基板との間の光路中の少なくとも一部分に位置する液体LQを介して露光を行う露光装置であって、液体の屈折率を調整するための屈折率調整手段を有する。



【特許請求の範囲】

【請求項１】レチクル上に設けられたパターンを照明する照明光学系と、該パターンの像を感光性基板上に形成する投影光学系とを有し、前記投影光学系と前記感光性基板との間の光路中の少なくとも一部分に位置する液体を介して露光を行う露光装置において、
前記液体の屈折率を調整するための屈折率調整手段を有することを特徴とする露光装置。

【請求項２】前記屈折率調整手段は、前記投影光学系の結像性能を補正するように前記液体の屈折率を調整することを特徴とする請求項１記載の露光装置。

【請求項３】前記投影光学系の結像性能を測定する結像性能測定手段をさらに備え、
前記屈折率調整手段は、前記結像性能を補正するように前記液体の屈折率を調整することを特徴とする請求項２記載の露光装置。

【請求項４】前記投影光学系の結像性能の変動の要因の状態を検知する変動要因検知手段をさらに備え、
前記屈折率調整手段は、前記要因の状態に応じて、前記結像性能を補正するように前記液体の屈折率を調整することを特徴とする請求項１記載の露光装置。

【請求項５】前記照明光学系は、前記レチクルに対する照明条件を変更可能に構成され、
前記変動要因検知手段は、前記照明条件の状態を検知し、
前記屈折率調整手段は、前記照明条件の変更に応じて、前記結像性能を補正するように前記液体の屈折率を調整することを特徴とする請求項４記載の露光装置。

【請求項６】前記変動要因検知手段は、前記レチクルの種類を判別するものであり、
前記屈折率調整手段は、前記レチクルの種類に応じて、前記結像性能を補正するように前記液体の屈折率を調整することを特徴とする請求項４記載の露光装置。

【請求項７】前記感光性基板を保持する感光性基板ホルダーをさらに備え、
該感光性基板ホルダーは、前記投影光学系と前記感光性基板との間の光路を前記液体で満たすための側壁と、前記液体を前記感光性基板ホルダーへ供給すると共に前記感光性基板ホルダーから回収するための供給・回収ユニットとを備えることを特徴とする請求項１乃至６の何れか一項記載の露光装置。

【請求項８】前記屈折率調整手段は、前記液体に屈折率を調整するための添加剤を供給する添加剤供給ユニットと、前記液体から前記添加剤を回収するための添加剤回収ユニットとを有することを特徴とする請求項１乃至７の何れか一項記載の露光装置。

【請求項９】所定の照明条件のもとでレチクルを照明する工程と、前記レチクル上に設けられたパターンを投影光学系を用いて感光性基板に転写する工程とを含み、前記投影光学系からの光を所定の液体を介して前記感光性基板へ導く露光方法において、
前記投影光学系の結像性能を補正するために、前記液体の屈折率を調整する工程を含むことを特徴とする露光方法。

【請求項１０】所定の照明条件のもとでレチクルを照明する工程と、前記レチクル上に設けられたデバイスパターンを投影光学系を用いて感光性基板に転写する工程とを含み、前記投影光学系からの光を所定の液体を介して前記感光性基板へ導くデバイス製造方法において、
前記レチクル及び前記照明条件のうち少なくとも一方が変更されたときに、前記液体の屈折率を変更することを特徴とするデバイス製造方法。

【請求項１１】レチクル上に設けられたパターンを照明する照明光学系と、該パターンの像を感光性基板上に形成する投影光学系とを有し、前記投影光学系と前記感光性基板との間の光路中の少なくとも一部分に位置する液体を介して露光を行う露光装置の製造方法において、
前記投影光学系の結像性能を測定する工程と、
該測定された結像性能に基づいて、前記液体の屈折率の初期値を定める工程とを含むことを特徴とする露光装置の製造方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、レチクル上に設けられたデバイスパターンのを感光性基板上に投影する投影光学系を備えた露光装置及び該露光装置を用いた露光方法並びにデバイス製造方法に関する。さらに詳しくは、本発明は投影光学系と感光性基板との間の光路に液体を充填した液浸型露光装置に関する。本発明は、半導体素子、撮像素子（ＣＣＤ等）、液晶表示素子、または薄膜磁気ヘッド等を製造する際に好適なものである。

【０００２】

【従来の技術】光学系の最終面と像面との間の空間を、ワーキングディスタンスと言うが、従来の露光装置の投影光学系ではワーキングディスタンスは空気で満たされていた。ところで、ＩＣやＬＳＩを製造する過程に於いてシリコンウエハに露光するパターンは、その微細化が常に望まれていて、そのためには露光に用いる光の波長を短くするか、あるいは像側の開口数を大きくする必要がある。光の波長が短くなるにつれ、満足できる結像性能を得つつ露光に満足な光量を確保できるだけの透過率を持つガラス材料は少なくなってくる。

【０００３】そこで像面までの最終媒質を、空気より屈折率の大きい、液体にすることで像側の開口数を大きくすることが提案されていて、そのように液体を用いた投影光学系を持つ露光装置は、液浸型露光装置と呼ばれている。さて、露光装置においては、投影光学系の結像性能を補正するために、投影光学系の最も物体側の光路或いは最も像側の光路中に、結像性能を調整するための結像性能補正部材を交換可能に設ける技術が知られてい

る。

【0004】

【発明が解決しようとする課題】しかしながら、液浸型露光装置では、投影光学系と感光性基板との間の光路（ワーキングディスタンス）に液体を満たす構成であるため、結像性能を補正するための部材を配置することが困難である。また、このような結像性能補正部材は、有限の数、現実的な装置の構成を考えると数個程度しか準備することができないため、離散的にしか結像性能を補正できない問題点がある。

【0005】また、投影光学系の結像性能は所定の許容範囲に収める必要があるが、上述のように結像性能の補正が離散的にしかできなければ、この所定の許容範囲内に収めることが困難となる。特に、露光パターンの微細化や露光面積の増大が求められると、この結像性能の許容範囲が狭くなり、また、レチクルと感光性基板とを走査させつつ露光を行う走査露光方法を行う場合にも結像性能特性の変動幅の許容範囲が狭くなっており、離散的な補正では対応しきれない。

【0006】また、上述のような結像性能補正部材の交換時において、投影光学系自体の振動が発生するため、結像性能へ悪影響が生じる恐れもある。そこで、本発明は、連続的な結像性能の補正を振動を伴うことなく可能とすることを第１の目的とする。また、本発明は、投影光学系の開口数の増大と結像性能を補正することとの両立を第２の目的とする。

【0007】

【課題を解決するための手段】上述の第１の目的を達成するために、本発明による露光装置は、レチクル上に設けられたパターンを照明する照明光学系と、このパターンの像を感光性基板上に形成する投影光学系とを有し、投影光学系と感光性基板との間の光路中の少なくとも一部分に位置する液体を介して露光を行う露光装置であって、液体の屈折率を調整するための屈折率調整手段を有するものである。

【0008】ここで、上記請求項２に掲げた好ましい態様によれば、屈折率調整手段は、前記投影光学系の結像性能を補正するように液体の屈折率を調整するものである。この構成に基づいて、請求項３に掲げた好ましい態様によれば、投影光学系の結像性能を測定する結像性能測定手段をさらに備えるものであり、屈折率調整手段は、前記結像性能を補正するように液体の屈折率を調整するものである。

【0009】また、請求項４に掲げた好ましい態様によれば、投影光学系の結像性能の変動の要因の状態を検知する変動要因検知手段をさらに備えるものであり、屈折率調整手段は、要因の状態に応じて、結像性能を補正するように液体の屈折率を調整するものである。この構成に基づいて、請求項５に掲げた好ましい態様によれば、照明光学系は、前記レチクルに対する照明条件を変更可能に構成され、変動要因検知手段は、照明条件の状態を検知し、屈折率調整手段は、照明条件の変更に応じて、結像性能を補正するように液体の屈折率を調整するものである。

【0010】そして、請求項６に掲げた好ましい態様によれば、変動要因検知手段は、レチクルの種類を判別するものであり、屈折率調整手段は、レチクルの種類に応じて、結像性能を補正するように液体の屈折率を調整するものである。また、上述の第２の目的を達成するためには、投影光学系と感光性基板との間の光路の全てを液体で満たすことが好ましい。このとき、本発明による露光装置は、投影光学系と感光性基板との間の光路を前記液体で満たすための側壁と、液体を前記感光性基板ホルダーへ供給すると共に前記感光性基板ホルダーから回収するための供給・回収ユニットとを備え、感光性基板を保持する感光性基板ホルダーをさらに有することが好ましい。

【0011】また、屈折率調整手段は、液体に屈折率を調整するための添加剤を供給する添加剤供給ユニットと、液体から前記添加剤を回収するための添加剤回収ユニットとを有することが好ましい。

【0012】

【発明の実施の形態】上述の構成のごとき本発明においては、投影光学系と感光性基板との間の光路中に位置する液体の屈折率を調整することができるため、この屈折率の変化により投影光学系の結像性能を補正することができる。ここで、屈折率調整の手法としては、液体が多物質の混合液体であるとすると、この混合液体の屈折率nは、ローレンツ・ローレンス（Lorentz-Lorenz）の式に従い、

【0013】

【数１】

$$\left(\frac{n^2-1}{n^2+2}\right)=\sum_{i=1,2,\cdots} m_{(i)}\times\left(\frac{{n_{(i)}}^2-1}{{n_{(i)}}^2+2}\right)\times\frac{\rho}{\rho_{(i)}}$$

【0014】となる。但し、

$n_{(i)}$：ｉ番目の物質の屈折率、

$m_{(i)}$：ｉ番目の物質の重量分率、

$\rho_{(i)}$：ｉ番目の物質の密度、

【0015】

【数２】

【0016】である。例えば液体を水溶液とすると、この水溶液の屈折率が水溶液自体の濃度に応じて変化するため、水溶液へ添加する物質の濃度を増減させれば良い。これにより、投影光学系の結像性能を補償できる屈折率の値となるように、液体の屈折率を変化させれば、投影光学系の結像性能は良好なものとなる。

【0017】ここで、屈折率の調整は、例えば投影光学系の収差などの結像性能を測定し、その結果に応じて屈折率を調整しても良く、投影光学系の結像性能の変動に対応している要因の変動を検知して、その結果に応じて屈折率を調整しても良い。前者の投影光学系の結像性能を測定する手法においては、露光装置の製造時に投影光学系の収差などを測定し、この収差を補償する屈折率の値を液体の屈折率の初期値に設定しても良い。このように製造時の調整の一部として屈折率を調整すれば、製造・調整が容易となる利点がある。また、露光装置自体に収差測定機構などを設けておき、この収差測定機構による収差測定結果に応じて、液体の屈折率を変更しても良い。

【0018】一方、後者の結像性能の変動に対応する要因の変動としては、レチクルの種類、照明条件の状態、投影光学系を通過する露光エネルギー量などが挙げられる。ここで、レチクルを照明する際の照明条件（σ値、変形照明か否かなど）は、レチクル上に設けられるパターンの種類によって最適なものが決まり、この照明条件が変わると、投影光学系の収差を初めとする結像性能が変化する。そこで、例えばレチクルの種類、照明条件などの要因ごとに、この要因の変動に伴って変化する結像性能を補償するための屈折率の値を予めメモリーなどに記憶させておき、この要因の変動を検知し、記憶された関係に基づいて液体の屈折率を調整すれば良い。また、投影光学系を通過する露光エネルギー量の大小により投影光学系の結像性能が変化する、いわゆる照射変動があるが、この場合においても、露光エネルギー量と、この露光エネルギー量の大小によって変化する結像性能を補償するための屈折率の値を予めメモリーなどに記憶させておき、この要因の変動を検知し、記憶された関係に基づいて液体の屈折率を調整すれば良い。なお、この手法において、メモリーに記憶させる代わりに、所定の計算式で算出しても良い。

【0019】このように、液体の屈折率を調整することで、投影光学系の結像性能のうち、特に球面収差、像面湾曲の補正に効果的である。以下、図面を参照して、本発明にかかる実施の形態について説明する。

［第1の実施の形態］図1は、本発明にかかる第1の実施の形態による露光装置を概略的に示す図である。尚、図1では、XYZ座標系を採用している。

【0020】図1において、光源Sは、例えば波長248nmの露光光を供給し、この光源Sからの露光光は、照明光学系IL及び反射鏡Mを介してレチクルRをほぼ均一な照度分布のもとで照明する。ここで、本例では光源Sとして、KrFエキシマレーザ光源を用いているが、その代わりに、193nmの露光光を供給するArFエキシマレーザ光源やg線、i線等を供給する高圧水銀ランプ等を用いても良い。また、図1では不図示ではあるが照明光学系ILは、面光源を形成するためのオプティカルインテグレータと、この面光源からの光を集光して被照射面を重畳的に均一照明するためのコンデンサ光学系と、オプティカルインテグレータにより形成される面光源の位置に配置されて面光源の形状を可変にするための可変開口絞りとを有するものである。ここで、面光源の形状としては、光軸から偏心した複数の面光源を持つもの、輪帯形状のもの、円形状であってその大きさがことなるものなどがある。このような照明光学系ILとしては、例えば米国特許第5，329，094号公報や米国特許第5，576，801号公報に開示されているものを用いることができる。

【0021】そして、レチクルRを通過・回折した露光光は、投影光学系Tを経てウエハW上に達し、ウエハ上には、レチクルRの像が形成される。ここで、レチクルRは、レチクルローダーRLによって保持され、レチクルローダーRLは任意の時にローダーテーブルLT上を駆動装置T1により、X軸及びY軸上で任意の速度で移動できるように構成されている。ここで、レチクルローダーRLのローダーテーブルLT上での移動速度は、速度センサーSSで検知され、この速度センサーSSからの出力は、第1制御部CPU1へ伝達される。

【0022】また、ウエハWは、ウエハテーブルWTにより保持されている。このウエハテーブルWTには、液体LQを溜めるための側壁が設けられている。本例では、この側壁により、ウエハWから投影光学系Tまでの光路の全てが液体LQで満たされる構成となっている。このウエハテーブルWTは、駆動装置T2によりホルダーテーブルHT上でX軸方向及びY軸方向に任意の速度で移動できるように構成されている。

【0023】ここで、上記の第1制御部CPU1は、レチクルローダーRLのローダーテーブルLT上での移動速度と、投影光学系Tの露光倍率βとからウエハテーブルWTのホルダーテーブル上での移動速度を算出し、駆動装置T2へ伝達する。駆動装置は、第1制御部CPU1から伝達された移動速度に基づいて、ウエハテーブルWTを移動させる。

【0024】図2は、このウエハテーブルWTの構成を詳細に表した図である。この図2において、投影光学系Tの最もウエハW側の光学部材と、投影光学系Tの金枠との間は、液体LQが浸透してこないように密着しているか、パッキングされている。また、ウエハテーブルWTの底部には、複数の開口が設けられており、これらの開口に接続されている配管Vから減圧することにより、ウエハWはウエハテーブルWTに吸着されている。そし

て、ウエハテーブルＷＴには、電極Ｄ１，Ｄ２が設けられており、これらの電極Ｄ１、Ｄ２のそれぞれの周囲には、イオン交換膜Ｉ１，Ｉ２が設けられている。これらのイオン交換膜Ｉ１，Ｉ２により、電極Ｄ１，Ｄ２の周囲と、露光光が液体ＬＱを通過する領域とが区切られる。ここで、電極Ｄ１の周囲の雰囲気はイオン交換膜Ｉ１と隔壁Ｋ１とにより密閉空間となっており、この密閉空間には排気管Ｈ１が接続されている。また、電極Ｄ２の周囲の雰囲気はイオン交換膜Ｉ２と隔壁Ｋ２とにより密閉空間となっており、この密閉空間には排気管Ｈ２が接続されている。これらの排気管Ｈ１、Ｈ２は、ともに混合器Ｋに接続されている。この混合器Ｋには、電磁弁ＤＶを備えた導入管ＬＤの一端が接続されており、この導入管ＬＤの他端は、ウエハテーブルＷＴの近傍に位置している。

【００２５】電極Ｄ１，Ｄ２への印可電圧は図示なき電源供給部から供給され、電源供給部が供給する印可電圧は、第２制御部ＣＰＵ２により制御される。また、電磁弁ＤＶの開閉に関してもは、第２制御部ＣＰＵ２が制御する。本例では、これらの電極Ｄ１，Ｄ２、イオン交換膜Ｉ１，Ｉ２、隔壁Ｋ１，Ｋ２、排気管Ｈ１，Ｈ２、混合器Ｋ、電磁弁ＤＶ、導入管ＬＤ、図示なき電源供給部、第２制御部ＣＰＵ２が屈折率調整手段を構成している。

【００２６】以下、屈折率調整手段の動作について説明する。以下の説明において、液体ＬＱは、純水に添加剤として塩化水素を加えたものであるとしている。まず、液体ＬＱの屈折率を下げる場合、第２制御部ＣＰＵ２は、電源供給部へ指令を送り、電極Ｄ１及び電極Ｄ２の間に所定の電圧を所定の時間だけ加印する。このとき、陽極となる電極からは酸素気体が発生し、陰極となる電極からは水素と塩素との混合気体が発生する。このとき、液体ＬＱにおける塩化水素濃度が下がるため、上記（１）式からもわかるように、液体ＬＱの屈折率が低下する。ここで、各々の電極Ｄ１，Ｄ２の近傍で発生した気体は、イオン交換膜Ｉ１，Ｉ２を通過しないため、排気管Ｈ１，Ｈ２を介して回収することが可能である。この回収された気体は、混合器Ｋへ送られる。混合器Ｋでは、回収された気体（酸素気体、水素気体、塩化水素気体）が混ぜ合わせられ、これより、液体ＬＱよりも高濃度の添加物水溶液が生成される。

【００２７】また、液体ＬＱの屈折率を上げる場合、第２制御部ＣＰＵ２は、電磁弁ＤＶを開いて高濃度の添加物水溶液を液体ＬＱへ加えるように、電磁弁ＤＶへ指令を送る。これにより、液体ＬＱの屈折率が上昇する。この構成により、液体ＬＱの屈折率を可変にできる。さて、第２制御部ＣＰＵ２に接続されているメモリーＭ１には、種々の照明条件ごとに対応して屈折率の値がテーブルの形で記憶されている。ここで、屈折率の値は、ある照明条件下において投影光学系Ｔで生じる収差を補正するために必要な液体ＬＱの屈折率の値である。また、このメモリーＭ１には、ある時点における液体ＬＱ中の添加物濃度の値が、常に更新される形で保管されている。

【００２８】また、上記の照明光学系ＩＬは、この照明光学系ＩＬが形成する面光源の形状に関する情報を第２制御部ＣＰＵ２へ伝達するために、第２制御部ＣＰＵ２と接続されている。ここで、照明条件一本例では面光源の形状一が変化すると、この情報は第２制御部ＣＰＵ２へ伝達される。このとき、第２制御部ＣＰＵ２は、伝達された照明条件に対応する屈折率の値をメモリーＭ１から検索し、その屈折率を実現するための添加物の濃度を上記（１）式から計算する。次に第２制御部ＣＰＵ２は、メモリーＭ１に保管されている現在の添加物濃度と、計算された添加物濃度とに従って、現在の添加物濃度を計算された添加物濃度とするように、電極Ｄ１，Ｄ２あるいは電磁弁ＤＶを制御する。

【００２９】これにより、液体ＬＱの屈折率の値は、液体ＬＱを含めたときの投影光学系Ｔの収差が補正されるものとなる。

［第２の実施の形態］第２の実施の形態は、第１の実施の形態における添加物をエチルアルコールとした点が大きく異なる。このエチルアルコールは、感光性基板としてのレジストが塗布されたウエハＷのレジスト層を溶解せず、投影光学系Ｔにおける最もウエハＷ側の光学部材（液体ＬＱと接する光学部材）及びこの光学部材に施された光学コートへの影響が少ない利点がある。

【００３０】また、第２の実施の形態においては、屈折率調整手段の構成が第１の実施の形態のものとは異なる。以下、図３を参照して屈折率調整手段の構成につき説明する。なお、図３において、図２に示したものと同じ機能を有する部材には、同じ符号を付してある。第２の実施の形態によるウエハテーブルＷＴを示す図３において、第１の実施の形態のものとは異なる点は、添加物を液体ＬＱへ供給するための添加物供給管ＬＳと、純水を液体ＬＱへ供給するための純水供給管ＷＳと、液体ＬＱがウエハテーブルＷＴから溢れないように液体ＬＱを排出する排出管Ｌとを有する点である。

【００３１】ここで、添加物供給管ＬＳ、純水供給管ＷＳ及び排出管Ｌには、添加物及び純水の供給量を調整するための電磁弁ＤＶＬＳ，ＤＶＷＳ及び液体ＬＱの排出量を調整するための電磁弁ＤＶＬがそれぞれ設けられており、これらの電磁弁ＤＶＬＳ，ＤＶＷＳ，ＤＶＬの開閉は、第２制御部ＣＰＵ２により制御されている。第２の実施の形態における屈折率調整時の動作について説明する。

【００３２】まず、液体ＬＱの屈折率を上げる場合、第２制御部ＣＰＵ２は電磁弁ＤＶＬＳを制御して、所定の量だけ添加物を液体ＬＱへ加える。このとき、排出管Ｌから液体ＬＱを所定の量だけ排出する。この排出する液

体ＬＱの量は、加えられた添加物の量と同じであることが好ましい。これにより、液体ＬＱ中の添加物濃度が高まり、その屈折率が上昇する。

【００３３】また、液体ＬＱの屈折率を下げる場合、第２制御部ＣＰＵ２は電磁弁ＤＶＷＳを制御して、所定の量だけ純水を液体ＬＱへ加える。このとき、排出管Ｌから液体ＬＱを所定の量だけ排出する。この排出する液体ＬＱの量は、加えられた純水の量と同じであることが好ましい。これにより、液体ＬＱ中の添加物濃度が低くなり、その屈折率が低下する。

【００３４】ここで、加えられる添加物及び純水の量、排出する液体ＬＱの量は、第２制御部ＣＰＵ２により制御される。なお、メモリーＭ１内に照明条件の種類に対応して屈折率の値が記憶される点、ある時点における液体ＬＱの添加物濃度の値が保管される点は、上述の第１の実施の形態と同様であり、これらの情報に基づいて、投影光学系Ｔの収差を補正できる屈折率を実現するための添加物濃度を計算する点も第１の実施の形態と同様である。

【００３５】このようにして、第２の実施の形態における第２制御部ＣＰＵ２は、メモリーＭ１に保管されている現在の添加物濃度と、計算された添加物濃度とに従って、現在の添加物濃度を計算された添加物濃度とするように、電磁弁ＤＶＬＳ，ＤＶＷＳ，ＤＶＬの開閉を制御する。これにより、液体ＬＱの屈折率の値は、液体ＬＱを含めたときの投影光学系Ｔの収差が補正されるものとなる。

［第３の実施の形態］次に、図４を参照して第３の実施の形態について説明する。第３の実施の形態による露光装置は、収差測定装置を備えている点で上述の第１及び第２の実施の形態とは異なる。なお、図４において、上述の図１～図３の例と同じ機能を有する部材には同じ符号を付してあり、図１と同様のＸＹＺ座標系を採用している。

【００３６】図４において、光源Ｓは、波長２４８ｎｍの露光光を供給し、この光源Ｓからの露光光は、ビーム整形光学系１１により所定形状の断面に整えられた後、第１フライアイレンズ１２に入射する。第１フライアイレンズ１２の射出側には、複数の光源像からなる２次光源が形成される。この２次光源からの露光光は、リレーレンズ系１３Ｆ，１３Ｒを経て第２フライアイレンズ１５へ入射する。このリレーレンズ系は前群１３Ｆ及び後群１３Ｒから構成され、これらの前群１３Ｆ及び後群１３Ｒの間には、被照射面上でのスペックルを防止するための振動ミラー１４が配置されている。

【００３７】さて、第２フライアイレンズ１５の射出面側には、第１フライアイレンズによる２次光源の像が複数形成され、これが３次光源となる。この３次光源が形成される位置には、所定の形状あるいは所定の大きさを持つ複数の開口絞りを設定できる可変開口絞り１６が配置されている。この可変開口絞り１６は、例えば図５に示すように、石英などで構成された透明基板上にパターニングされた６つの開口絞り１６ａ～１６ｅをターレット状に設けたものである。ここで、円形開口を持つ２つの開口絞り１６ａ，１６ｂは、σ値（投影光学系の開口数に対する照明光学系の開口数）を変更するための絞りであり、輪帯形状を持つ２つの開口絞り１６ｃ，１６ｄは、互いに輪帯比の異なる絞りである。そして、残りの２つの開口絞り１６ｅ，１６ｆは、４つの偏心した開口を有する絞りである。この可変開口絞り１６は、可変開口絞り駆動ユニット１７により、複数の開口絞り１６ａ～１６ｆのうち何れか一つが光路内に位置するように駆動される。

【００３８】図４に戻って、可変開口絞り１６からの露光光は、コンデンサレンズ系１８により集光されてレチクルブラインド１９上を重畳的に照明する。レチクルブラインド１９は、リレー光学系２０Ｆ，２０Ｒに関してレチクルＲのパターン形成面と共役に配置されており、レチクルブラインド１９の開口形状によりレチクルＲ上での照明領域の形状が決定される。レチクルブラインド１９からの露光光は、リレー光学系の前群２０Ｆ、反射鏡Ｍ及びリレー光学系の後群２０Ｒを介してレチクルＲ上の所定の位置に実質的に均一な照度分布の照明領域を形成する。

【００３９】なお、前述の第１及び第２の実施の形態における照明光学系ＩＬは、この実施の形態に示したビーム整形光学系１１～リレー光学系２０Ｆ，２０Ｒを適用することもできる。さて、レチクルＲは、レチクルローダーＲＬ上に載置されており、このレチクルローダーＲＬは、ホルダーテーブルＬＴ上で図中ＸＹ方向及びＺ軸を中心とした回転方向（θ方向）に移動可能となっている。このレチクルローダーＲＬには、移動鏡ＲＩＭが設けられており、レチクル干渉計ＲＩは、レチクルローダーＲＬのＸＹ方向及びθ方向の位置を検出する。また、レチクルローダーＲＬは、レチクルローダー駆動ユニットＲＬＤによりＸＹ方向及びθ方向へ駆動される。ここで、レチクル干渉計ＲＩからの出力は、第１制御部ＣＰＵ１へ伝達され、第１制御部ＣＰＵ１は、レチクルローダー駆動ユニットＲＬＤを制御する構成となっている。

【００４０】また、図示なきレチクルストッカーからの搬送路の途中には、レチクルＲに設けられたバーコードを読みとるためのバーコードリーダーＢＲが設けられている。このバーコードリーダーＢＲが読みとったレチクルＲの種類に関する情報は、第２制御部ＣＰＵ２へ伝達される。ここで、第２制御部ＣＰＵ２に接続されているメモリーＭ１には、レチクルＲの種類ごとに最適な照明条件に関する情報と、レチクルＲの種類ごとに最適な液体ＬＱの屈折率の値とが記憶されている。

【００４１】レチクルＲの下側には、所定の縮小倍率｜β｜を有する投影光学系Ｔが設けられており、この投影

光学系Ｔの最もウエハ面側の光学部材とウエハＷとの間には、液体ＬＱが介在している。投影光学系Ｔは、この液体ＬＱを介してウエハ面上にレチクルＲの縮小像を形成する。ウエハＷは、ウエハテーブルＷＴに吸着固定されており、このウエハテーブルＷＴは、ウエハテーブルＷＴ自体のＺ軸方向への移動やティルト（Ｚ軸に対する傾き）を行わせるためのＺアクチュエータＺＤ１，ＺＤ２，ＺＤ３を介して、定盤に対してＸＹ方向に移動可能なウエハステージＷＴＳに取り付けられている。このウエハステージＷＴＳは、ウエハステージ駆動ユニットＷＤにより駆動される。また、ウエハテーブルの側壁は鏡面加工が施されており、この部分がウエハ干渉計ＷＩの移動鏡となっている。ここで、ウエハステージ駆動ユニットＷＤの駆動は上述の第１制御部ＣＰＵ１で制御され、ウエハ干渉計ＷＩからの出力は第１制御部ＣＰＵ１へ伝達される構成となっている。

【００４２】また、投影光学系Ｔには、投影光学系ＴとウエハＷとの間のＺ方向の距離を測定するためのフォーカスセンサＡＦが設けられている。このフォーカスセンサＡＦは、投影光学系ＴにおけるウエハＷ側に近い光学素子を介してウエハ面上に光を照射し、かつウエハで反射された光を上記光学素子を介して受光し、その受光位置により投影光学系ＴとウエハＷとの間のＺ方向の距離を測定するものである。このようなフォーカスセンサＡＦの構成は、例えば特開平6-66543号公報に開示されている。

【００４３】さて、第３の実施の形態においても、添加物保管部ＬＳＴに貯蔵される高濃度の添加物水溶液を液体ＬＱへ供給するための添加物供給管ＬＳと、純水保管部ＷＳＴに貯蔵される純水を液体ＬＱへ供給するための純水供給管ＷＳとを備えており、添加物供給管ＬＳ及び純水供給管ＷＳには、添加物水溶液及び純水の供給量を調整するための電磁弁ＤＶＬＳ，ＤＶＷＳが設けられている。また、ウエハテーブルＷＴには、液体ＬＱがウエハテーブルから溢れないように液体ＬＱを排出するための排出管Ｌが設けられており、この排出管Ｌには、液体ＬＱの排出量を調整するための電磁弁が設けられている。これらの電磁弁ＤＶＬＳ，ＤＶＷＳ，ＤＶＬの開閉は、上述の第２の実施の形態と同様に、第２制御部ＣＰＵ２により制御されている。

【００４４】また、ウエハテーブルＷＴ上には、投影光学系の収差を測定するための収差測定部ＡＳと、液体ＬＱの添加物濃度を検出するための添加物濃度検出部ＤＳとが設けられている。ここで、収差測定部ＡＳとしては、例えば特開平6-84757号公報に開示されているものを用いることができる。ここで、収差測定部ＡＳ及び添加物濃度検出部ＤＳからの出力は、第２制御部ＣＰＵ２へ伝達される。また、添加物濃度検出部ＤＳからの出力は、第２制御部ＣＰＵ２を介してメモリーＭ１へある時点における液体ＬＱの添加物濃度の値として保管される。

【００４５】次に、第３の実施の形態の動作について説明する。まず、図示なきレチクルストッカーからレチクルＲが取り出されてレチクルローダーＲＬ上に載置される途中に、バーコードリーダーＢＲは、レチクルＲに設けられているバーコードを読み取り、その情報を第２制御部ＣＰＵ２へ伝達する。第２制御部ＣＰＵ２は、メモリーＭ１に記憶されているレチクルＲの種類に対応した照明条件に関する情報を読み出し、その情報に従って、可変開口絞り駆動ユニット１７を制御して開口絞り１６ａ～１６ｆのうちの所定の一つを光路内に位置させる。また、第２制御部ＣＰＵ２は、メモリーＭ１に記憶されている液体ＬＱの屈折率の値に基づいて、その屈折率を実現するための添加物の濃度を上記（１）式から計算する。その後、添加物濃度検出部ＤＳにより検出されてメモリーＭ１に保管されている現在の添加物濃度と、計算された添加物濃度とに従って、現在の添加物濃度を計算された添加物濃度とするように、電磁弁ＤＶＬＳ，ＤＶＷＳ，ＤＶＬの開閉を制御する。

【００４６】これにより、液体ＬＱの屈折率の値は、液体ＬＱを含めたときの投影光学系Ｔの収差が補正されるものとなる。この後、フォーカスセンサＡＦによりウエハＷのＺ方向の位置及びティルトを検出して、ウエハＷが所要の位置になるようにＺアクチュエータＺＤ１，ＺＤ２，ＺＤ３を駆動する。この状態において、光源Ｓからの露光光を照明光学系を介してレチクルＲへ導き、第１制御部ＣＰＵ１は、レチクル干渉計ＲＩ及びウエハ干渉計ＷＩによりレチクルＲ及びウエハＷの位置を検出しつつ、レチクルローダー駆動ユニットＲＬＤ及びウエハステージ駆動ユニットＷＤを駆動させ、レチクルＲ及びウエハＷを投影光学系Ｔの投影倍率｜β｜の速度比の元で移動させる。これにより、レチクルＲ上のパターンは、良好な結像状態のもとでウエハＷ上へ転写される。

【００４７】さて、投影光学系Ｔの結像性能（収差など）は、常に一定ではなく、温度変化や大気圧変化、投影光学系Ｔが露光光を吸収することによる温度上昇などにより変化する場合がある。そこで、第３の実施の形態では、収差測定部ＡＳにより実際の投影光学系Ｔの収差（結像性能）を測定し、この測定結果に基づいて液体ＬＱの屈折率の値を調整する構成としている。

【００４８】具体的には、第３の実施の形態では、メモリーＭ１内に投影光学系の収差値に対応させた形で、その収差を補正できる液体ＬＱの屈折率の値が記憶されている。そして、収差測定部ＡＳにより検出された投影光学系Ｔの収差は、第２制御部ＣＰＵ２へ伝達される。第２制御部ＣＰＵ２は、メモリーＭ１内に記憶されている液体ＬＱの屈折率の値を読み出し、この屈折率の値になるように添加物濃度を上記（１）式より求め、液体ＬＱがその添加物濃度となるように電磁弁ＤＶＬＳ，ＤＶＷＳ，ＤＶＬの開閉を制御する。

【００４９】この構成により、投影光学系Ｔの環境変化（温度変化、大気圧変動、露光光吸収による変動）があってもその結像性能を良好に維持することができる。なお、この収差測定部ＡＳによる測定は、常時行う必要はなく、所定の周期ごとに行えば良い。

［第４の実施の形態］次に図６を参照して、第４の実施の形態について説明する。第４の実施の形態は、投影光学系とウエハとの間の光路の全てを液体で満たす構成ではなく、この光路の一部を液体で満たす構成としたものである。

【００５０】図６（ａ），（ｂ）において、図１～３に示した第１及び第２の実施の形態と同じ機能を有する部材には同じ符号を伏してある。図６（ａ），（ｂ）に示す第４の実施の形態では、ウエハホルダーＷＴの側壁により液体ＬＱを溜める代わりに、露光光を透過させる材料（例えば石英など）で構成された容器Ｃ１，Ｃ２中に液体ＬＱを満たす構成が前述の第１及び第２の実施の形態とは異なる。この構成により、前述の第１及び第２の実施の形態が有していた効果のうち、開口数増大または実効的焦点深度拡大の効果はないものの、連続的に投影光学系Ｔの収差（結像性能）調整が可能となる効果は有している。

【００５１】なお、この第４の実施の形態において、液体ＬＱが入れられている容器Ｃ１，Ｃ２を投影光学系Ｔと一体に設けても良い。以上の第１～第４の実施の形態では、液体ＬＱとして純水を用いたが純水に限られることはない。

【００５２】

【発明の効果】以上に示したように本発明によれば、投影光学系の結像性能を振動なく連続的に調整をすることができる。また、開口数の増大（或いは実効的な焦点深度の拡大）と結像性能の調整とを両立させることが可能となる。

【図面の簡単な説明】

【図１】本発明の第１及び第２の実施の形態にかかる露光装置を全体的に示す概略図である。

【図２】本発明の第１の実施の形態にかかる露光装置の要部を示す断面図である。

【図３】本発明の第２の実施の形態にかかる露光装置の要部を示す断面図である。

【図４】本発明の第３の実施の形態にかかる露光装置を示す概略図である。

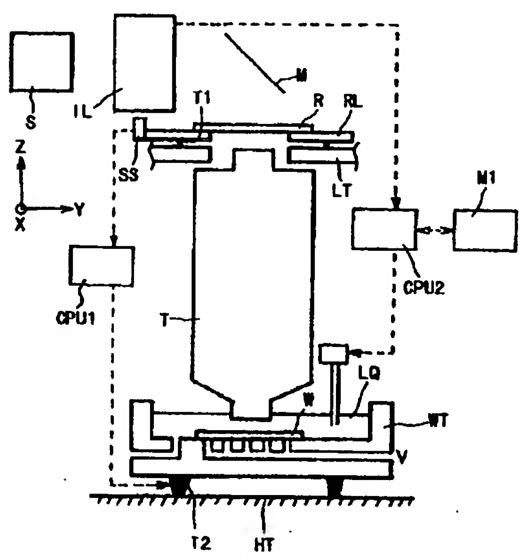
【図５】本発明の第３の実施の形態にかかる露光装置の一部を示す概略図である。

【図６】本発明の第４の実施の形態にかかる露光装置の要部を示す断面図である。

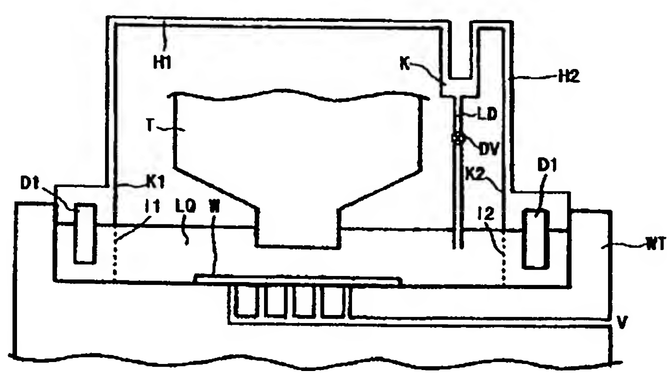
【符号の説明】

Ｓ…光源	Ｔ２…駆動装置
ＩＬ…照明光学系	Ｍ１…メモリー
Ｍ…反射板	Ｖ…減圧管
Ｔ…投影光学系	Ｄ１、Ｄ２…電極
Ｗ…ウエハ	Ｉ１，Ｉ２…イオン交換膜
ＬＱ…液体	Ｋ１，Ｋ２…隔壁
Ｒ…レチクル	Ｈ1，Ｈ２…配管
ＲＬ…レチクルローダー	Ｌ…排出管
ＬＴ…ローダーテーブル	ＬＤ…導入管
ＳＳ…センサー	ＷＳ…純水供給管
ＷＴ…ウエハテーブル	Ｌ Ｓ…添加物供給管
Ｔ１…駆動装置	

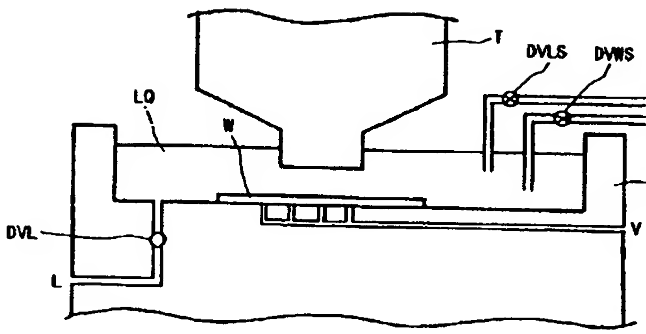
【図１】



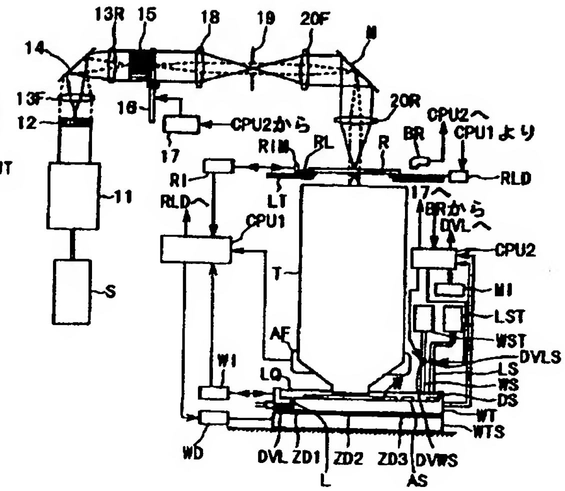
【図２】



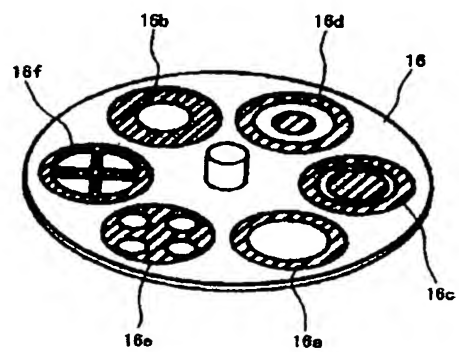
【図３】


T
DVLS
DVWS
LS
WS
LQ
W
WT
DVL
V
L

【図４】

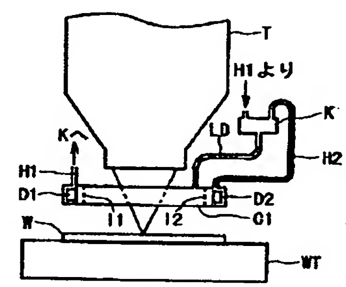

13R
15
18
19
20F
M
14
13F
12
16
17
CPU2から
20R
CPU2へ
BR
CPU1より
RIM
RL
R
RI
RLD
LT
RLDへ
CPU1
17へ
BRから
DVLへ
CPU2
11
S
T
MI
LST
WST
DVLS
AF
LS
WS
DS
WI
LQ
W
WT
WTS
WD
DVL
ZD1
ZD2
ZD3
DVWS
L
AS

【図５】

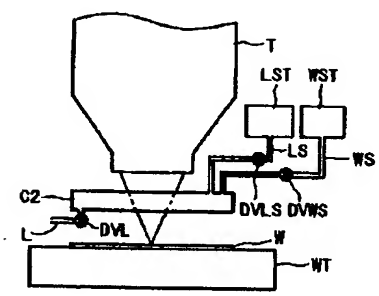

16b
16d
16f
16
16c
16e
16a

【図６】

(a)


T
H1より
K
Kへ
LD
H2
H1
D1
D2
I1
I2
C1
W
WT

(b)


T
LST
WST
LS
WS
C2
DVLS
DVWS
L
DVL
W
WT

(54) [Title of the Invention] EXPOSURE APPARATUS, ITS MANUFACTURING AND EXPOSURE METHOD, AND DEVICE MANUFACTURING METHOD

(57) [Abstract]

[Problem] To enable continuous correction of image forming performance without vibration, or achieve an increase in the numerical aperture of a projection optical system and the correction of image forming performance.

[Solution] An exposure apparatus having an illumination optical system IL for illuminating a pattern provided on a reticle R and a projection optical system T for forming an image of the pattern on a photosensitive substrate, which performs exposures through a liquid LQ located at least part of an optical path between the projection optical system and the photosensitive substrate, wherein the exposure apparatus further comprising refractive index adjusting means for adjusting the refractive index of the liquid.

[Claims]

[Claim 1] An exposure apparatus having an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and which performs exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the exposure apparatus comprising:

refractive index adjusting means for adjusting the refractive index of the liquid.

[Claim 2] The exposure apparatus according to claim 1, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance of the projection optical system.

[Claim 3] The exposure apparatus according to claim 2, further comprising

image forming performance measuring means for measuring the image forming performance of the projection optical system,

wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance.

[Claim 4] The exposure apparatus according to claim 1, further comprising

variable factor sensing means for sensing the state of the factor causing a fluctuation in the image forming

performance of the projection optical system,

wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the state of the factor.

[Claim 5] The exposure apparatus according to claim 4, wherein

the illumination optical system is configured to be able to change the illumination conditions for the reticle,

the variable factor sensing means senses the state of the illumination conditions, and

the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the change in the illumination conditions.

[Claim 6] The exposure apparatus according to claim 4, wherein the variable factor sensing means discriminates the kind of reticle, and

the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the kind of reticle.

[Claim 7] The exposure apparatus according to any one of claims 1 through 6, further comprising

a photosensitive substrate holder for holding the photosensitive substrate,

wherein the photosensitive substrate holder includes a side wall for filling the liquid in an optical path between the projection optical system and the

photosensitive substrate, and a supply/recovery unit for supplying the liquid to the photosensitive substrate holder and recovering the liquid from the photosensitive substrate holder.

[Claim 8] The exposure apparatus according to any one of claims 1 through 7, wherein the refractive index adjusting means includes an additive supply unit for supplying an additive for adjusting the refractive index of the liquid and an additive recovery unit for recovering the additive from the liquid.

[Claim 9] An exposure method, including a step of illuminating a reticle under predetermined illumination conditions and a step of transferring a pattern provided on the reticle to a photosensitive substrate using a projection optical system, in which light from the projection optical system is guided to the photosensitive substrate through a predetermined liquid, the method comprising:

a step of adjusting the refractive index of the liquid to correct the image forming performance of the projection optical system.

[Claim 10] A device manufacturing method, including illuminating a reticle under predetermined illumination conditions and a step of transferring a device pattern provided on the reticle to a photosensitive substrate using a projection optical system, in which light from the projection optical system is guided to the photosensitive

substrate through a predetermined liquid, wherein

when at least either the reticle or the illumination conditions is changed, the refractive index of the liquid is changed.

[Claim 11] A method for manufacturing an exposure apparatus provided with an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and provided for performing exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the method comprising:

a step of measuring the image forming performance of the projection optical system, and

a step of determining an initial value for the refractive index of the liquid based on the measured image forming performance.

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to an exposure apparatus equipped with a projection optical system for projecting a device pattern provided on a reticle to the surface of a photosensitive substrate, an exposure method using the exposure apparatus and device manufacturing method. More particularly, the present invention relates to an immersion exposure apparatus in which the optical path between the projection optical

system and a photosensitive substrate is filled with a liquid. The present invention is suitably used for manufacturing semiconductor devices, image pickup devices (such as CCDs), liquid crystal display devices, thin film magnetic heads, or the like.

[0002]

[Prior Art] A space between the last or front face of an optical system and an image surface is called working distance. The working distance of a projection optical system in the conventional exposure apparatus is filled with air. With ever increasing demand for finer patterns to be exposed to a silicon wafer in the process of manufacturing ICs or LSIs, it is necessary to make the exposure wavelength shorter or increase the numerical aperture on the image side. The shorter the light wavelength, the less the glass materials having satisfactory image forming performance and transmittance enough to ensure a satisfactory amount of exposure light.

[0003] Therefore, use of a liquid having a refractive index larger than that of air as the last medium to the image plane to increase the numerical aperture on the image side has been proposed. An exposure apparatus having a projection optical system using such a liquid is called an immersion exposure apparatus. On the other hand, there is known an exposure apparatus technique for providing an exchangeable image forming performance-correcting element in an optical path of the projection optical system closest

to the object side or the image side to adjust image forming performance in order to correct the image forming performance of the projection optical system.

[0004]

[Problems to be Solved by the Invention] However, since the immersion exposure apparatus is configured to fill a liquid in the optical path (working distance) between the projection optical system and the photosensitive substrate, it is difficult to arrange such an element to correct image forming performance. Further, since only a finite number of image forming performance-correcting elements, about a few pieces in consideration of practical exposure apparatus design, can be prepared, there also arises a problem that can correct image forming performance only in a discrete manner.

[0005] The image forming performance of the projection optical system also needs to fall within a predetermined allowable range, but the discrete correction of the image forming performance makes it difficult for the image forming performance to fall within the predetermined allowable range. Especially, as the exposure pattern is required to be finer or the exposed area is required to be larger, the allowable range of the image forming performance is narrowed. Even using such a scanning exposure method to perform exposures while scanning the reticle and the photosensitive substrate, since the allowable range of changes in image forming performance

characteristics is narrowed, the discrete correction is insufficient.

[0006] In addition, during replacement of image forming performance-correcting elements, vibration occurs in the projection optical system itself, and this could adversely affect the image forming performance. Therefore, it is a first object of the present invention to enable continuous correction of image forming performance without vibration. It is a second object of the present invention to achieve an increase in the numerical aperture of a projection optical system and the correction of image forming performance.

[0007]

[Means for Solving the Problems] In order to attain the first object of the present invention, there is provided an exposure apparatus having an illumination optical system for illuminating a pattern provided on a reticle and a projection optical system for forming an image of the pattern on a photosensitive substrate, and which performs exposures through a liquid located at least part of an optical path between the projection optical system and the photosensitive substrate, the exposure apparatus comprising refractive index adjusting means for adjusting the refractive index of the liquid.

[0008] According to a preferred embodiment as set forth in claim 2, the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming

performance of the projection optical system. According to another preferred embodiment as set forth in claim 3 based on the above structure, the exposure apparatus further comprises image forming performance measuring means for measuring the image forming performance of the projection optical system, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance.

[0009] According to still another preferred embodiment as set forth in claim 4, the exposure apparatus further comprises variable factor sensing means for sensing the state of the factor causing a fluctuation in the image forming performance of the projection optical system, wherein the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the state of the factor. According to yet another preferred embodiment as set forth in claim 5 based on the above structure, the illumination optical system is configured to be able to change the illumination conditions for the reticle, the variable factor sensing means senses the status of the illumination conditions, and the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the change in the illumination conditions.

[0010] According to yet another preferred embodiment as set forth in claim 6, the variable factor sensing means

discriminates the kind of reticle, and the refractive index adjusting means adjusts the refractive index of the liquid to correct the image forming performance according to the kind of reticle. Further, in order to attain the above-mentioned second object, it is preferable that the liquid be filled in the entire range of the optical path between the projection optical system and the photosensitive substrate. In this case, it is preferably that the exposure apparatus according to the present invention should include a side wall for filling the liquid in the optical path between the projection optical system and the photosensitive substrate and a supply/recovery unit for supplying the liquid to the photosensitive substrate holder and recovering the liquid from the photosensitive substrate holder, and further include a photosensitive substrate holder for holding the photosensitive substrate.

[0011] It is also preferable that the refractive index adjusting means should include an additive supply unit for supplying an additive for adjusting the refractive index of the liquid and an additive recovery unit for recovering the additive from the liquid.

[0012]

[Embodiments of the Invention] In the structures of the present invention as mentioned above, since the refractive index of the liquid located in the optical path between the projection optical system and the photosensitive substrate can be adjusted, the image forming performance of the

projection optical system can be corrected according to the change in the refractive index. In a refractive index adjusting technique, if the liquid is a mixed liquid of multiple substances, the refractive index n of the mixed liquid is determined according to the Lorentz-Lorenz formula:

[0013]

[Eq. 1]

$$\left(\frac{n^2-1}{n^2+2}\right) = \sum_{i=1,2,\ldots} m_{(i)} \times \left(\frac{n_{(i)}{}^2-1}{n_{(i)}{}^2+2}\right) \times \frac{\rho}{\rho_{(i)}}$$

[0014] In this equation,

[0015]

[Eq. 2]

$n_{(i)}$ is the refractive index of the i-th substance,

$m_{(i)}$ is the weight fraction of the i-th substance, and

$\rho_{(i)}$ is the concentration of the i-th substance.

[0016] For example, if the liquid is an aqueous solution, the refractive index of the aqueous solution varies according to the concentration of the aqueous solution itself. Therefore, the concentration of the substances added to the aqueous solution can be increased or decreased. Thus, the refractive index of the liquid can be changed to have a refractive index value enough to compensate the image forming performance of the projection optical system in order to optimize the image forming performance of the projection optical system.

[0017] The adjustment of refractive index can be made, for example, by measuring image forming performance such as aberration of the projection optical system to adjust the refractive index according to the measurement result. Alternatively, a fluctuation in a factor corresponding to a fluctuation in the image forming performance of the projection optical system can be sensed to adjust the refractive index according to the sensing result. In the former technique for measuring the image forming performance of the projection optical system, aberration or the like of the projection optical system can be measured during manufacturing of the exposure apparatus to set a refractive index value enough to compensate for the aberration as an initial value for the refractive index of the liquid. The adjustment of the refractive index in part of the adjustment process during manufacturing has the advantage of making adjustment and manufacturing work easy. In addition, an aberration measuring mechanism can also be provided in the exposure apparatus itself to change the refractive index of the liquid according to the result of aberration measurement by the aberration measuring mechanism.

[0018] On the other hand, in the latter technique, the kind of reticle, the status of illumination conditions, the amount of energy passing through the projection optical system or the like is considered to be the factor in which a fluctuation corresponding to the fluctuation in image

forming performance occurs. Here, since the illumination conditions (σ value, whether it is distorted illumination or not, etc.) for illuminating a reticle are optimized depending on the kind of pattern provided on the reticle, the image forming performance of the projection optical system including its aberration is changed when the illumination conditions are changed. A refractive index value for compensating the image forming performance varying with a fluctuation in each factor such as the kind of reticle or each of the illumination conditions is prestored in a memory or the like on a factor basis, so that a fluctuation in the factor can be sensed to adjust the refractive index of the liquid based on the stored relation. The image forming performance of the projection optical system also varies as the amount of exposure energy passing through the projection optical system increases or decreases, called projection fluctuation. In this case, the amount of exposure energy and a refractive index value for compensating the image forming performance varying with an increase or decrease in the amount of exposure energy are also prestored in a memory or the like, so that a fluctuation in this factor can be sensed to adjust the refractive index of the liquid based on the stored relation. In this technique, the refractive index value may be calculated according to a predetermined formula instead of being prestored in a memory.

[0019] The adjustment of the refractive index of the liquid

is effective in correcting the image forming performance of the projection optical system, especially spherical aberration or image surface curvature. The following describes preferred embodiments of the present invention with reference to the drawings.

[First Embodiment] FIG. 1 is a schematic diagram showing an exposure apparatus according to a first embodiment of the present invention. In FIG. 1, an XYZ coordinate is employed.

[0020] In FIG. 1, a light source S supplies exposure light having a wavelength of 248nm. The exposure light from the light source S illuminates the reticle R through an illumination optical system IL and a reflecting mirror M with a substantially uniform luminance distribution. In the embodiment, a KrF excimer-laser light source is used as the light source S, but any other type of light source may be used, such as an ArF excimer-laser light source supplying exposure light having a wavelength of 193nm or a high-pressure mercury lamp supplying g- or i-line light. Though not shown in FIG. 1, the illumination optical system IL has an optical integrator for forming a surface light source, a condenser optical system for condensing light from the surface light source to illuminate a projected surface uniformly in a superimposed manner, and a variable aperture stop arranged in the position of the surface light source formed by the optical integrator so that it will vary the shape of the surface light source. As the shape of the surface light source, a shape having a plurality of surface

light sources eccentric from the optical axis, the shape of an annular zone, various circular shapes of different sizes, etc, are used. As the illumination optical system IL, an illumination optical system disclosed, for example, in US Patent No. 5,329,094 or US Patent No. 5,576,801 can be used.

[0021] The exposure light that passed through the reticle R and was diffracted reaches the surface of the wafer W through a projection optical system T and forms an image of the reticle R on the wafer. The reticle R is held by a reticle loader RL. The reticle loader RL is capable of being driven by a drive unit T1 to move on a loader table LT along the X and Y axes at any speed at any time as required. The moving speed of the reticle loader RL on the loader table LT is sensed by a speed sensor SS, and the output of the speed sensor SS is sent to a first control part CPU 1.

[0022] The wafer W is held by a wafer table WT. The wafer table WT is provided with a side wall for pooling the liquid LQ. In the embodiment, the side wall allows the entire optical path from the wafer W to the projection optical system T to be filled with the liquid LQ. The wafer table WT is capable of being driven by a drive unit T2 to move on a holder table HT at any speed in the directions along the X and Y axes.

[0023] The first control part CPU 1 calculates the moving speed of the wafer table WT on the holder table from the moving speed of the reticle loader RL on the loader table

LT and the exposure magnification β of the projection optical system T to send the calculated moving speed to the drive unit T2. The drive unit moves the wafer table WT based on the moving speed sent from the first control part CPU 1.

[0024] FIG. 2 is a view showing a detailed configuration of the wafer table WT. In FIG. 2, the optical part closet to the wafer W side in the projection optical system T and a metal frame of the projection optical system T are brought into tight contact with each other without any clearance, or packing is inserted in the clearance. A plurality of openings are also provided in the bottom portion of the wafer table WT to draw the wafer W by suction on the wafer table WT by decreasing the pressure from piping V connected to these openings. Further, electrodes D1, D2 are provided in the wafer table WT, and ion exchange membranes I1, I2 are provided around these electrodes D1, D2, respectively. These ion exchange membranes I1, I2 separate the region around each of the electrodes D1, D2 from a region in which the exposure light passes through the liquid LQ. The atmosphere around the electrode D1 is an enclosed space by means of the ion exchange membrane I1 and a dividing wall K1, and an exhaust pipe H1 is connected to the enclosed space. The atmosphere around the electrode D2 is also an enclosed space by means of the ion exchange membrane I2 and a dividing wall K2, and an exhaust pipe H2 is connected to the enclosed space. These exhaust pipes H1, H2 are

connected to a mixing unit K. One end of an inlet tube LD equipped with an electromagnetic valve DV is connected to the mixing unit K, and the other end of the inlet tube LD is located near the wafer table WT.

[0025] Applied voltage to the electrodes D1, D2 is supplied from a power supply unit, not shown, and the applied voltage supplied from the power supply unit is controlled by a second control part CPU 2. The opening and closing of the electromagnetic valve DV is also controlled by the second control part CPU 2. In the embodiment, the electrodes D1, D2, the ion exchange membranes I1, I2, the dividing walls K1, K2, the exhaust pipes H1, H2, the mixing unit K, the electromagnetic valve DV, the inlet tube LD, the power supply unit, not shown, and the second control part CPU 2 constitute refractive index adjusting means.

[0026] The following describes the operation of the refractive index adjusting means. In the following description, the liquid LQ is pure water with hydrogen chloride added in it as an additive. First, when the refractive index of the liquid LQ should be reduced, the second control part CPU 2 sends an instruction to the power supply unit to apply a predetermined voltage between the electrode D1 and the electrode D2 for a predetermined period of time. During this period, oxygen gas is generated from the electrode on the anode side and a gas mixture of hydrogen and chlorine is generated from the electrode on the cathode side. Since the concentration of hydrogen

chloride in the liquid LQ is reduced, the refractive index of the liquid LQ is also reduced as apparent from the above equation (1). The gases respectively generated near the electrodes D1, D2 do not pass through the ion exchange membranes I1, I2, so that they can be recovered through the exhaust pipes H1, H2. The recovered gases are sent to the mixing unit K. In the mixing unit K, the recovered gases (oxygen gas, hydrogen gas, and hydrochloric gas) are mixed to generate an additive aqueous solution with a solute concentration higher than the liquid LQ.

[0027] On the other hand, when the refractive index of the liquid LQ is increased, the second control part CPU 2 sends an instruction to the electromagnetic valve DV to open so that the high-concentration additive aqueous solution will be added to the liquid LQ to increase the refractive index of the liquid LQ. This structure makes it possible to vary the refractive index of the liquid LQ. A refractive index value for each of various illumination conditions is stored in the form of a table in a memory M1 connected to the second control part CPU 2. The refractive index value is the refractive index of the liquid LQ required to correct aberration caused in the projection optical system T under a corresponding illumination condition. In the memory M1, an additive concentration value in the liquid LQ at a certain point of time is held and updated.

[0028] The illumination optical system IL is connected to the second control part CPU 2 to send the second control

part CPU 2 information relating to the shape of the surface light source formed by the illumination optical system IL. when an illumination condition, that is, the shape of the surface light source in this embodiment, is changed, this information is sent to the second control part CPU 2. The second control part CPU 2 retrieves a refractive index value corresponding to the sent illumination condition from the memory M1, and calculates an additive concentration according to the above equation (1) to achieve the refractive index. Then, based on the current additive concentration stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 controls the electrodes D1, D2 or the electromagnetic valve DV to change the current additive concentration to the calculated additive concentration.

[0029] Thus, the refractive index of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ.

[Second Embodiment] A major point in a second embodiment that differs from the first embodiment is that the second embodiment uses ethyl alcohol as the additive. Ethyl alcohol has the advantages of not dissolving the resist layer of the wafer W coated with a resist to form a photosensitive substrate, and less influence on the optical part closest to the wafer W side in the projection optical system T (that is, the optical part contacting the liquid LQ) and the optical coating on the optical part.

[0030] In addition, the structure of the refractive index adjusting means in the second embodiment is different from that in the first embodiment. Referring to FIG. 3, the structure of the refractive index adjusting means will be described below. Note that in FIG. 3 parts or members having the same functions as those in FIG. 2 are given the same reference numerals and symbols. In FIG. 3 showing the wafer table WT according to the second embodiment, points different from the first embodiment are that an additive supply pipe LS for supplying an additive to the liquid LQ, a pure water supply pipe WS for supplying pure water to the liquid LQ, and an exhaust pipe L for discharging the liquid LQ to prevent an overflow of the liquid LQ from the wafer table WT are provided.

[0031] Electromagnetic valves DVLS, DVWS are provided in the additive supply pipe LS and the pure water supply pipe WS, respectively, to adjust the supply of the additive and the pure water, and an electromagnetic valve DVL is provided in the exhaust pipe L to adjust the amount of discharge of the liquid LQ. The opening and closing of these electromagnetic valves DVLS, DVWS, DVL is controlled by the second control part CPU 2. The following describes the operation of adjusting the refractive index in the second embodiment.

[0032] First, when the refractive index of the liquid LQ is increased, the second control part CPU 2 controls the electromagnetic valve DVLS to add a prescribed amount of

additive to the liquid LQ. At this time, the liquid LQ is discharged by a prescribed amount through the exhaust pipe L. It is preferable that the amount of discharge of the liquid LQ be equal to the amount of additive added to the liquid LQ. This increases the additive concentration in the liquid LQ and hence the refractive index.

[0033] On the other hand, when the refractive index of the liquid LQ is reduced, the second control part CPU 2 controls the electromagnetic valve DVWS to add a prescribed amount of pure water to the liquid LQ. At this time, the liquid LQ is discharged by a prescribed amount through the exhaust pipe L. It is preferable that the amount of discharge of the liquid LQ be equal to the amount of pure water added to the liquid LQ. This reduces the additive concentration in the liquid LQ and hence the refractive index.

[0034] The amounts of added additive and pure water, and the amount of discharge of the liquid LQ are controlled by the second control part CPU 2. The other points that a refractive index value for each of various illumination conditions is stored in the memory M1, an additive concentration value in the liquid LQ at a certain point of time is held, and an additive concentration is calculated based on these pieces of information to achieve a refractive index that can correct the aberration of the projection optical system T are the same as in the first embodiment.

[0035] Then, based on the current additive concentration stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 in the second embodiment controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration to the calculated additive concentration. Thus, the refractive index value of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ.

[Third Embodiment] Referring next to FIG. 4, a third embodiment will be described. An exposure apparatus according to the third embodiment is different from the first and second embodiments in that it is provided with an aberration measuring device. Note that in FIG. 4 parts or members having the same functions as those in FIGS. 1 to 3 are given the same reference numerals and symbols, and the same XYZ coordinate system as in FIG. 1 is employed.

[0036] In FIG. 4, the light source S supplies exposure light having a wavelength of 248nm. The exposure light from the light source S is shaped by a beam shaping optical system 11 into a predetermined cross section, and is incident on a first fly-eye lens 12. Secondary light sources consisting of a plurality of light source images are formed on the exit side of the first fly-eye lens 12. The exposure light from the secondary light sources is incident on a second fly-eye lens 15 through a relay lens system 13F, 13R. This relay lens system includes a front

group 13F and a rear group 13R, and a vibration mirror 14 is arranged between the front and rear groups to prevent the occurrence of speckles on the projected surface.

[0037] Images of the plurality of secondary light sources formed through the first fly-eye lens are formed as tertiary light sources on the exit surface side of the second fly-eye lens 15. A variable aperture stop 16 capable of setting a plurality of aperture stops having predetermined shapes or sizes is arranged at a position in which the tertiary light sources are formed. For example, as shown in FIG. 5, the variable aperture stop 16 has six aperture stops 16a-16e patterned in the form of a turret on a transparent substrate made of quartz and the like. Among these aperture stops, two aperture stops 16a, 16b each having a circular opening are to change the σ value (the numerical aperture of the illumination optical system relative to the numerical aperture of the projection optical system), and two aperture stops 16c, 16d each having the shape of an annular zone are different in the proportion of annular zones. The remaining two aperture stops 16e, 16f have four eccentric openings, respectively. The variable aperture stop 16 is driven by a variable aperture stop driving unit 17 to locate any one of the plurality of aperture stops 16a-16f in the optical path.

[0038] Returning to FIG. 4, the exposure light from the variable aperture stop 16 is condensed by a condenser lens system 18 to illuminate a reticle blind 19 in a

superimposed manner. The reticle blind 19 is conjugated with a pattern formed surface of the reticle R with respect to a relay optical system 20F, 20R so that the shape of the illuminated area on the reticle R will be defined depending on the shape of the opening of the reticle blind 19. The exposure light from the reticle blind 19 forms an illuminated area in a predetermined position on the reticle with a substantially uniform luminance distribution through the front-group relay optical system 20F, a reflecting mirror M, and the rear-group relay optical system 20R.

[0039] Note that the illumination optical system IL in the above first and second embodiments can also be replaced with the structure from the beam shaping optical system 11 to the relay optical system 20F, 20R in this embodiment. The reticle R is loaded on a reticle loader RL. The reticle loader RL can move on the holder table LT not only in the X and Y directions but in the direction of rotation about the Z axis (θ direction) as shown in the figure. A moving mirror RIM is provided in the reticle loader RL, and a reticle interferometer RI detects the position of the reticle loader RL in the XY and θ directions. The reticle loader RL is driven by a reticle loader driving unit RLD in the XY and θ directions. The output of the reticle interferometer RI is sent to the first control part CPU 1 so that the first control part CPU 1 will control the reticle loader driving unit RLD.

[0040] A barcode reader BR for reading a barcode provided

on a reticle R is provided at some midpoint in a transport track from a reticle stocker, not shown. Information on the kind of reticle R obtained from the barcode read by the barcode reader BR is sent to the second control part CPU 2. Here, information relating to the optimum illumination condition for each kind of reticle R and the optimum refractive index value of the liquid LQ for each kind of reticle R are stored in the memory M1 connected to the second control part CPU 2.

[0041] The projection optical system T having a predetermined reduction ratio $|\beta|$ is provided underneath the reticle R, and the liquid LQ lies between the optical part closest to the wafer surface side in the projection optical system T and the wafer W. the projection optical system T forms a reduced image of the reticle R on the wafer surface through the liquid LQ. The wafer W is fixed by suction on the wafer table WT. The wafer table WT is mounted on a wafer stage WTS through Z actuators ZD1, ZD2, ZD3 for actuating the wafer table WT to move in the Z direction or tilt (with respect to the Z axis). The wafer stage WTS is movable in the XY directions with respect to a base. The wafer stage WTS is driven by a wafer stage driving unit WD. The side wall of the wafer table is mirror-finished, and this mirror-finished portion serves as a moving mirror for a wafer interferometer WI. The wafer stage driving unit WD is controlled by the first control part CPU 1, and the output of the wafer interferometer WI is sent to the first

control part CPU 1.

[0042] A focus sensor AF is provided in the projection optical system T to measure the distance in the Z direction between the projection optical system T and the wafer W. The focus sensor AF projects a beam to the wafer surface through the optical element closest to the wafer W side in the projection optical system T, and receives a reflected beam from the wafer through the optical element to measure the distance in the Z direction between the projection optical system T and the wafer W based on the beam receiving position. The structure of such a focus sensor AF is disclosed, for example, in Japanese Patent Laid-Open No. 06-66543.

[0043] The additive supply pipe LS for supplying to the liquid LQ a high-concentration additive aqueous solution stored in an additive storage unit LST, and the pure water supply pipe WS for supplying to the liquid LQ pure water stored in a pure water storage unit WST are also provided in the third embodiment. Likewise, the electromagnetic valves DVLS, DVWS are provided in the additive supply pipe LS and the pure water supply pipe WS, respectively, to adjust the amounts of supply of the additive aqueous solution and the pure water, respectively. Further, the exhaust pipe L is provided in the wafer table WT to discharge the liquid LQ in order to prevent an overflow of the liquid LQ from the wafer table. The electromagnetic valve is also provided in the exhaust pipe L to adjust the

amount of discharge of the liquid LQ. The opening and closing of these electromagnetic valves DVLS, DVWS, DVL is controlled by the second control part CPU 2 in the same manner as in the above second embodiment.

[0044] In addition, an aberration measuring part AS for measuring the aberration of the projection optical system and an additive concentration detecting part DS for detecting the additive concentration of the liquid LQ are provided on the wafer table WT. A component disclosed, for example, in Japanese Patent Laid-Open No. 06-84757 can be used as the aberration measuring part. The output of the aberration measuring part AS and the additive concentration detecting part DS is sent to the second control part CPU 2. The output of the additive concentration detecting part DS is stored in the memory M1 through the second control part CPU 2 as an additive concentration value of the liquid LQ at a certain point of time.

[0045] The following describes the operation of the third embodiment. First, the barcode reader BR reads the barcode provided on the reticle R at some midpoint between when the reticle R was pulled out of the reticle stocker, not shown, and when it is loaded on the reticle loader RL, and sends the information to the second control part CPU 2. The second control part CPU 2 then reads the information relating to the illumination condition corresponding to the kind of reticle R stored in the memory M1, and controls the variable aperture stop driving unit 17 based on the

information to locate a corresponding one of the aperture stops 16a-16f in the optical path. Then, based on the refractive index value of the liquid LQ stored in the memory M1, the second control part CPU 2 calculates an additive concentration required to achieve the refractive index according to the above equation (1). After that, based on the current additive concentration detected by the additive concentration detecting part DS and stored in the memory M1 and the calculated additive concentration, the second control part CPU 2 controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration to the calculated additive concentration.

[0046] Thus, the refractive index value of the liquid LQ is adjusted to correct the aberration of the projection optical system T including the liquid LQ. After that, the focus sensor AF detects the position and tilt of the wafer W in the Z direction to drive the Z actuators ZD1, ZD2, ZD3 in order to move the wafer W to a required position. Under this condition, the exposure light from the light source S is guided to the reticle R through the illumination optical system. The first control part CPU 1 controls the reticle interferometer RI and the wafer interferometer WI to detect the position of the reticle R and the wafer W, while it actuates the reticle loader driving unit RLD and the wafer stage driving unit WD to move the reticle R and the wafer W with a speed ratio corresponding to the reduction ratio $|\beta|$.

This makes it possible to transfer the pattern on the reticle R to the surface of the wafer W under good imaging conditions.

[0047] The image forming performance (such as aberration) of the projection optical system T does not always constant, that is, it could vary with a temperature change, an atmospheric pressure change, or a temperature rise caused by the projection optical system T absorbing the exposure light. Therefore, in the third embodiment, the aberration measuring part AS measures the actual aberration (image forming performance) of the projection optical system T to adjust the refractive index of the liquid LQ based on the measurement result.

[0048] Specifically, in the third embodiment, a refractive index value of the liquid LQ enough to correct the aberration is stored in the memory M1 in association with the aberration value of the projection optical system. The aberration of the projection optical system T detected by the aberration measuring part AS is sent to the second control part CPU 2. The second control part CPU 2 reads the refractive index value of the liquid LQ stored in the memory M1, calculates an additive concentration to achieve the refractive index value according to the above equation (1), and controls the opening and closing of the electromagnetic valves DVLS, DVWS, DVL to change the current additive concentration of the liquid LQ to the calculated additive concentration.

[0049] This structure makes it possible to keep the image forming performance in good condition even if an environmental change (temperature change, atmospheric pressure change, or fluctuation caused by absorption of exposure light) occurs in the projection optical system T. Note that the aberration measuring part AS does not need to perform measurements at all times, that is, it has only to perform measurements at every predetermined interval.

[Fourth Embodiment] Referring next to FIG. 6, a fourth embodiment will be described. An exposure apparatus according to the fourth embodiment is configured to fill the liquid in part of the optical path between the projection optical system and the wafer, rather than in the entire optical path.

[0050] In FIGS. 6(a), (b), parts or members having the same functions as those in the first and second embodiments shown in FIGS. 1-3 are given the same reference numerals and symbols. In the fourth embodiment shown in FIGS. 6(a), (b), a point different from the first and second embodiments is that the liquid LQ is filled in cases C1, C2 made of a material (such as quartz) capable of allowing the exposure light to pass through, instead of pooling the liquid LQ by means of the side wall of the wafer holder WT. Among the advantages of the first and second embodiments, the structure of this embodiment does not have the advantages of increasing the numerical aperture and the effective depth of focus, but it has the advantage of being

able to continuously adjust the aberration (image forming performance) of the projection optical system T.

[0051] In the fourth embodiment, the cases C1, C2 containing the liquid LQ may be provided integrally with the projection optical system T. In the aforementioned first-fourth embodiments, pure water is used as the liquid LQ, but the liquid LQ is not limited to the pure water.

[0052]

[Effects of the Invention] As described above, according to the present invention, the image forming performance of the projection optical system can be adjusted continuously without vibration. It is also possible to achieve an increase in numerical aperture (or an increase in the effective depth of focus) and the adjustment of image forming performance.

[Brief Description of the Drawings]

[FIG. 1] It is a schematic diagram showing the overall structure of an exposure apparatus according to first and second embodiments of the present invention.

[FIG. 2] It is a sectional view showing the main part of the exposure apparatus according to the first embodiment of the present invention.

[FIG. 3] It is a sectional view showing the main part of the exposure apparatus according to the second embodiment of the present invention.

[FIG. 4] It is a schematic diagram showing an exposure apparatus according to a third embodiment of the present

invention.

[FIG. 5] It is a schematic view showing part of the exposure apparatus according to the third embodiment of the present invention.

[FIG. 6] It is a sectional view showing the main part of the exposure apparatus according to the third embodiment of the present invention.

[Description of Notations]

S ··· Light Source T2 ··· Drive Unit

IL ··· Illumination Optical System M1 ··· Memory

M ··· Reflecting Plate V ··· Decompression Pipe

T ··· Projection Optical System D1, D2 ··· Electrodes

W ··· Wafer I1, I2 ···Ion Exchange Membrane

LQ ··· Liquid K1, K2 ··· Dividing Wall

R ··· Reticle H1, H2 ···Piping

RL ··· Reticle Loader L ···Exhaust Pipe

LT ··· Loader table LD ···Inlet Tube

SS ··· Sensor WS ··· Pure Water Supply Pipe

WT ··· Wafer Table LS ···Additive Supply Pipe

T1 ··· Drive Unit